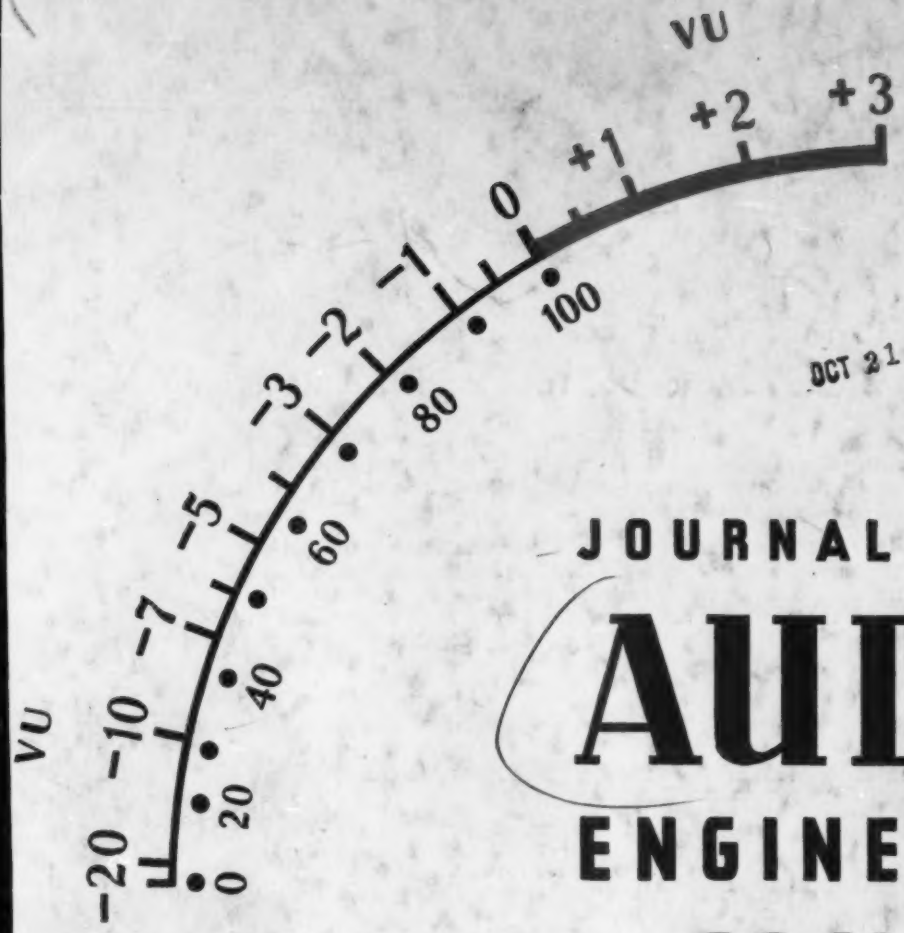

OCT 21 1957

JOURNAL OF THE AUDIO ENGINEERING SOCIETY

Tentative Program of the

Ninth Annual AES Convention

New York Trade Show Building

October 8-12, 1957

VOLUME 5 NUMBER 1 JANUARY 1957

ANNOUNCEMENT OF LECTURE SERIES

AES Fourth Lecture Series

"The Principles and Practices of Tape and Disk Recording"

The Audio Engineering Society is pleased to announce the presentation of a series of 30 weekly lectures on this subject. The over-all supervision of the conduct and content of this Series is in the capable hands of Mr. F. Sumner Hall, a past President of this Society.

Each two-hour lecture, delivered by an outstanding authority in his field, will be given on consecutive Thursday evenings at 7:15 P.M., beginning October 24, 1957. RCA Institutes, Inc., 350 West Fourth Street, New York City, has generously donated the use of its facilities for this Series. For further information, please write to Mr. F. Sumner Hall, Lecture Series Chairman, Amityville, New York, or to the offices of the Society.

The tentative titles and lecturers of the first group of lectures are given below. The content of the second group of 15 lectures will be announced shortly.

FIRST GROUP OF LECTURES — TENTATIVE TITLES AND LECTURERS

1. Oct. 24 PHILOSOPHY OF AUDIO SIGNAL TRANSMISSION
   Price E. Fish, Columbia Broadcasting System
2. Oct. 31 THE HUMAN EAR AND SOUND PERCEPTION
   J. Donald Harris, Submarine Base, New Londan
3. Nov. 7 STUDIO ACOUSTICAL REQUIREMENTS
   Leo L. Beranek, Bolt, Beranek & Newman
4. Nov. 14 MICROPHONES AND THEIR PLACEMENT
   Arthur C. Davis, Cinema Engineering Co., and Philip C. Erhorn, Audiofax Associates
5. Nov. 21 AUDIO FACILITIES SYSTEMS
   John D. Colvin, The Daven Company
6. Dec. 5 RECORDING FACILITIES SYSTEMS
   Stephen F. Temmer, Gotham Audio Development Co.
7. Dec. 12 THE OBSERVATION OF DISTORTION
   John D. Goodell, Riverside Research Laboratories
8. Dec. 19 ELECTRICAL MEASUREMENTS
   Norman H. Crowhurst, Audio Design Service
9. Jan. 2 MECHANICAL RECORDING — A SURVEY
   H. E. Roys and R. C. Moyer, RCA Victor Record Division
10. Jan. 9 MAGNETIC RECORDING — A SURVEY
    Marvin Camras, Armour Research Foundation
11. Jan. 16 REPRODUCTION
    W. O. Stanton, Pickering and Co.
12. Jan. 23 ACOUSTICAL MEASUREMENTS
    Lewis S. Goodfriend, Editor, *NOISE Control*
13. Jan. 30 MULTI-CHANNEL SYSTEMS, I
    Richard H. Ranger, Rangertone, Inc.
14. Feb. 6 MULTI-CHANNEL SYSTEMS, II
    B. P. Bogert, Bell Telephone Laboratories, Inc.
15. Feb. 13 MISCELLANY AND SUMMARY
    Helmuth Etzold, American Foundation for the Blind

JOURNAL OF THE AUDIO ENGINEERING SOCIETY

GEORGE HORIUCHI, Editor

VOLUME 5 - 1957 NUMBERS 1-4

Journal of the AUDIO ENGINEERING SOCIETY

JANUARY 1957 VOLUME 5, NUMBER 1

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Date of Publication: October 4, 1957

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Journal of the Audio Engineering Society, Volume 5, Number 1, January 1957. Published quarterly by the Audio Engineering Society and supplied to all members in good standing. Publication office, 104 Liberty Street, Utica, N. Y. Executive and editorial office, P. O. Box 12, Old Chelsea Station, New York 11, N. Y. Entered as second class matter at the post office at Utica, N. Y. Subscription to nonmembers, $8 per year. Address manuscripts and all editorial correspondence to George Horiuchi, Columbia University, 632 West 125 Street, New York 27, N. Y.

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Editorial Comment

THE ADVENT of a new Editor is a most opportune time to take stock. Our Society has never been flourishing more successfully. The figures submitted by our Secretary show a steadily increasing membership. Examination of the schedule of the forthcoming Convention printed elsewhere in this issue indicates more papers and more speakers than ever before. The increasing popular interest in matters audio implies a corresponding acceleration of activity on the engineering level. This is also borne out by a parallel growth in the PGA Section of the I.R.E. Our own Sections, on the West Coast, in Japan, a new one in Pittsburgh, are steadily growing. In short, the AES is doing very well.

Doing very well, that is, with the exception of publication. In assuming the Editorship, I am confronted by a Journal with a noteworthy reputation except in one respect: it is behind in its publication date by a better part of a year. This has caused justifiable unhappiness and dissatisfaction on the part of our members, subscribers, the officers of the Society, the Publications Committee, and the Editor. In fact, no one is happy. It is therefore quite obvious that my main task will be to "catch up". Perhaps this can be accomplished by the end of this year; most likely it will be early next year. In any case I must ask all of you for forbearance the next few months, and, if you are in a position to help, for your active cooperation.

Our contributors, upon whom the Journal depends most heavily, can aid our publication effort materially. In the past (as well as now) an excessive amount of editorial time and labor has been spent in the revision of manuscripts. In no small way this has contributed to our falling behind. We have found it a rare occasion to receive a manuscript which is free from the need for extensive revision, either with respect to content or to exposition. If, in the future, authors will expend extra effort to minimize the necessity for revision, much time could be saved. Similarly, when manuscripts are returned for revision, if they could be resubmitted revised without delay, publication would be expedited.

In order to supply our authors with a kind of check list, I am reprinting in another section of this issue a paper by a specialist in technical writing. His remarks and advice are especially pertinent to the writing of the kind of technical papers we print. If a prospective author could follow these suggestions in the preparation of his paper, and carefully observe the technical details as to format and presentation which are specified on the 3rd Cover Page, my work would be simplified considerably.

With the same thought in mind, I should like to call attention to the other paper being reprinted in this issue. The main reasons for its appearance in the Journal are set forth in the remarks which immediately precede the paper. The reason for mentioning it here is to emphasize how its lucid, concise style typifies good technical writing. Its content is of high caliber, the language is precise, it is not written "down", and yet it is understandable. Not every paper appearing in these pages relates to world-shaking discoveries or inventions; nevertheless, every paper worth printing deserves to be a model of good technical expression.

Commencing with this issue, the Journal will endeavor to bring to the attention of its members other significant papers of audio engineering interest which are currently appearing in journals elsewhere. Since the Journal is nominally a quarterly, it is evident that few such papers can be considered for reprinting. Therefore preference will be given to those papers to which the majority of our members will not have ready access. Other papers which cannot be reproduced in their entirety will be summarized or abstracted.

We are also aware that many important papers appear in languages other than English. Being limited in our translating facilities, we invite our bilingual members to submit short abstracts in English of such papers for inclusion in these pages.

I will welcome your comments on this innovation, and will gratefully acknowledge your suggestions for future issues.

The principal sources of papers for the Journal are the two Conventions, the one in New York in the fall and the West Coast meeting early the following year. Numerous meetings are held by the individual Sections throughout the year, in which papers are frequently delivered. Yet very few of the latter are ever submitted for Journal consideration. May I ask the Section Chairmen to use more vigorous methods in persuading their speakers to send in their manuscripts? It is difficult to believe that none of the papers delivered before an AES audience are fit to publish!

Speaking of Sections, I should like to welcome the new Pittsburgh Section which came into being recently. To judge from their Section Reports, it is an eager, active organization whose numbers are steadily growing. We congratulate AES Member and Section Secretary, Emerson Boardman, who has in a large measure been responsible for the success of the Society in the Pittsburgh area.

G. HORIUCHI

The Audio-visual Requirements of the Overseas Missionary*

HAROLD GALLINA†

Board of Foreign Missions of the Presbyterian Church, U. S. A., New York, N. Y.

The ever-increasing use of audio-visual aids by overseas mission personnel emphasizes the need for equipment which will meet the vagaries of foreign operations. This paper describes (1) the effects of uncertain power and climatic conditions upon audio equipment, (2) the technical services offered by the author's organization, and (3) new devices designed to meet special requirements for overseas use such as (a) a playback attachment for 16mm magnetically striped film, (b) a simplified tape recorder attachment for synchronizing dialogue to a slide or film-strip projector, and (c) a mobile audio-visual unit.

INTRODUCTION

THE OVERSEAS missionary is faced with many difficult problems in the utilization of audio-visual equipment designed and manufactured in the U.S.A. There are problems arising from varying power conditions—the multiplicity of voltages and frequencies, poor voltage stabilization and even the problem of having no utility power generating station available at all. There are problems peculiar to overseas climatic conditions—high humidity, high temperatures, dampness, insects, and fungus. And there are problems of equipment transportation over rough roads and jungle trails, and of its subsequent maintenance when spare parts are all too few and often impossible to obtain without a delay of weeks and months. All these go to make the missionary's work overseas much more difficult than that of the local church audio-visual worker.

BASIC EQUIPMENT

Prior to his departure for his assigned field the missionary who is going to specialize in audio-visual work commonly purchases the following items of equipment:

> 35mm camera, 35mm slide-filmstrip projector (300- or 500-watt lamp with blower cooling), 35mm kerosene-operated slide and filmstrip projector, screen, 3-speed electric phonograph, radio receiving set (broadcast and short wave bands), and tape recorder (non-professional).

In areas where mission audio-visual centers are functioning, the missionary has additional equipment available for his use:

> 16mm sound motion picture projectors, 16mm cameras, public address system, and engine-driven generators.

With this basic equipment in mind, we are ready to consider in some detail the problems relative to its use.

PROBLEMS ENCOUNTERED

Power

Depending on the area, power may vary in voltage from below 100 volts to some 250 volts (both ac and dc, unstabilized). Therefore, voltage regulators and step-down transformers (adjustable resistors for dc) are necessary in order to meet equipment requirements. In the case of phonographs, for instance, low voltage greatly affects the driving torque of the turntable motors. Tape drives of recorders are similarly affected. This results in variation of the audio playback pitch. Tape recorders equipped with solenoids frequently fail to operate under low voltage.

In addition, there is the question of current. When ac equipment must operate from a dc source, a converter (motor-generator type when the load is great) or an inverter (vibrator type, for smaller loads) is required.

Public utility power frequencies vary from country to country—e.g., 25, 40, 42, 45, 50 and 60 cps. As a result, synchronously operated equipment, such as phonographs, tape recorders, some 16mm sound motion-picture projectors are affected. Motor driving spindles or pulley ratios must be altered in order to meet the standard speed requirements of such machines. Furthermore, these modifications must

* Paper presented at the Seventh Annual Convention of the Audio Engineering Society, New York, October 12, 1955. Revised manuscript received April 17, 1957.

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be reversible so that, when the missionary returns to the U. S. on furlough, or is assigned to another country where U. S. conditions exist, the equipment may be restored to its original state.

Climatic Problems

When it comes to the question of climatic conditions there are other problems.

For tropical use, phonographs, tape recorders, sound movie projectors, public-address systems, converters, etc. must be especially treated with a high-dielectric, moisture-proof coating, and in some geographical locations, fungus-proofing must also be included. Sealing by this process of all wiring, insulation, capacitors, resistors, terminal boards, etc. and the use of hermetically sealed electrical components is recommended.

Experience further indicates that Rochelle salt pickup cartridges are not practical in areas where temperature and humidity are relatively high—even becoming inoperable within a short period of time. Replacing them with the ceramic, or the variable reluctance type (with a slight circuit modification), remedies such inadequacies. Similarly, microphones equipped with Rochelle salt crystals are not recommended.

Demands Upon U. S. Church Boards

Facing the increased use of audio-visual tools by overseas personnel and the many adjustment demands to make these tools operable under the varying area conditions, U. S. Church mission boards were compelled to organize audio-visual departments for the channeling of technical counsel and the purchasing and maintenance of equipment stock.

A minimum list of such stock would include the following:

> Cameras and accessories, film, and darkroom supplies, sound motion-picture projectors, 35mm slide and filmstrip projectors (electrical and kerosene), opaque projectors, projection screens and bulbs, tape recorders and tape, phonographs, radio receiving sets (broadcast and short wave bands), and gasoline driven generators.

However, as the cooperative audio-visual program developed among the various major denominational mission groups overseas, there arose the need for a central supply organization in the United States. This need resulted in the establishment in 1949 of RAVEMCCO. Currently, it represents 16 different Protestant denominations with work throughout the world. Its headquarters are at 156 Fifth Avenue, New York City—where it maintains a staff of technical and programming advisers for its many overseas radio and recording projects.

TECHNICAL RESPONSIBILITIES

In this paper we are largely concerned with the need for *technical* assistance and the manner in which that need is currently handled by RAVEMCCO. One responsibility of the RAVEMCCO technical staff is to counsel outgoing missionaries on recommended audio-visual equipment and estimated equipment costs. A second is to serve as purchasing agent for such equipment. A third is to evaluate, for overseas use, new models as they are released by manufacturers. And fourth, finally, to develop new electrical and mechanical items to meet the various needs peculiar to the use of audio-visual equipment under unpredictable overseas conditions. This makes an extensive total of RAVEMCCO responsibilities. We shall consider in some detail only three of these.

Equipment Evaluation

In order that equipment may be flexible and that breakdowns and maintenance may be minimized, new models of machines and accessories are examined and tested to see that they meet certain electrical, mechanical and optical requirements, before being recommended for overseas use. The RAVEMCCO technical staff checks for the following:

a. Electrical requirements. Non-hygroscopic insulation, sealed or molded capacitors, conservative resistor ratings, at least two inputs (low gain and high gain), at least one voltage output and one power output terminal, provision for headphone or loudspeaker monitoring,[1] electric eye or VU meter for visual monitoring, a tone control adequate to compensate for audio playback deficiencies, a frequency range of 50 to 8000 cps at 7.5 ips,[1] at least 5 watts output, (less than 5% harmonic distortion for portable phonographs and tape recorders and less than 2% for recording studio and radio station equipment).

b. Mechanical requirements. Low flutter and wow,[1] easily manipulated lever controls, simple mechanical drives, a minimum of gadgets, mechanical linkages, and automatic stops, etc., fast forward and rewind speeds,[1] tape counter,[1] adequately ventilated and supported motors, standard 2-pole input and output phone-type jacks.

c. Optical requirements. Stable focusing means, adequate projector output and distribution, low temperature at film gate, low blower noise, relatively simple and adequately protected springs and parts on slide and film strip attachments.

Purchasing

Two RAVEMCCO projects will serve as specific illustrations of the varying nature of our overseas problems with regard to equipment purchase.

In January 1955 a professional recording studio was

[1] For tape recorders.

opened in Tokyo, Japan under the sponsorship of AVACO (Audio Visual Aids Committee of the National Christian Council of Japan). This studio, among other projects, was to handle large-scale disc and tape recording of sacred music, radio programs, etc. It was equipped with four RCA disc cutters, one Ampex tape recorder, Model 350, and one Ampex, Model 400. An RCA studio console was used to mix the several audio sources into the recorders.

However, because of the unstable power frequency in Tokyo, a special power supply controlled by a tuning fork oscillator also had to be provided in order to adequately drive the recording equipment at constant speed. A commercial air conditioner had to be installed to control the atmosphere in the vicinity of the disc cutter.

In December, 1954, RAVEMCCO's second Christian radio station HLKY went on the air in Seoul, Korea. (The first such station—DTSR—located in Dumaguete City, Philippines, was inaugurated in August of 1950.) Initial problems of HLKY were aggravated by the fact that the bulk of the broadcasting equipment (including RCA transmitting equipment, tower, antenna, etc.) was on the high seas bound for Korea in the summer of 1950. With the beginning of the war it had to be shunted to Japan for safekeeping. It was in storage there, until the end of the war four years later made trans-shipment to Korea possible. One of the preliminary essentials to getting HLKY on the air was to check the equipment for possible damage after so long a period of storage.

In Seoul, the problem of voltage stabilization was a major one and continues to be so. Power lines are greatly overtaxed. Proper equipment adjustment and operation requires the use of a voltage regulating transformer. Overvoltage relays are necessary in order to protect all station equipment from excessive line voltage surges.

New Equipment Developments

The RAVEMCCO staff also gives time to developing new ways of meeting some of these problems. We include here three examples.

1. Playback Attachment for Striped 16mm Film

There has been a steady and appreciable increase in the use of American-made and English-made 16mm religious sound motion picture films all over the world. Nationals of many countries are finding such films very interesting, but their final value is somewhat lessened by the fact that audiences are unable to understand English. As a result, a local interpreter must translate simultaneously with the English.

Magnetic striping of such films with an oxide coating 0.050″ in width is a partial answer to this problem. This method retains the optical track while making possible the recording of a new synchronous sound track in the native tongue. However, this would require each missionary who uses a 16mm sound optical projector to purchase a new 16mm magnetic projector. This is too expensive to be widely practical.

Therefore the author set out to develop a 16mm magnetic attachment that could be readily fastened to any good standard-make projector without the need for drilling, special tools or technical ability. To be practical, such a device had to be simple, reliable, small in size, easy to install and to keep aligned to the sound track. It would be placed in the immediate vicinity of the optical sound drum so as to insure good sound synchronization with the motion picture as projected on the screen. The device also had to maintain sound synchronization on tracks recorded on other standard magnetic projectors, thus making magnetic films interchangeable.

In September 1954 a device designed to meet these requirements was submitted to the United States Patent Office, Fig. 1. It consists of a combined film guide-post and head-assembly directing the film in the immediate vicinity of the optical sound drum of the projector. The guide post is less than ⅜ inch in diameter. The head supporting member is so constructed as to allow for head adjustment in four directions with respect to the guide post. This is necessary in order to properly align the head to a standard 16mm magnetic sound track, in addition to assuring proper film tension (with oxide coating in contact with the head) without the use of pressure pads, Fig. 2. This type of guide-post further provides a means of minimizing ill effects usually caused by warped film.

Adding this attachment to a standard optical projector

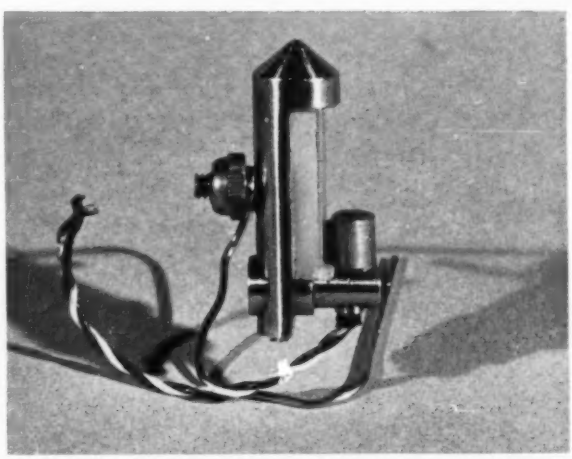

FIG. 1. Playback attachment for striped 16mm film, side view. The guidepost head, the support head, and the guide way are shown.

FIG. 2. Playback attachment with 0.100" striped film engaged.

does not affect the optical sound system, Fig. 3. It is therefore possible to play back optical and magnetic sound tracks simultaneously. This allows a translator to listen to the optical sound track (by headphones) while viewing the projected picture, and to record his translations onto the magnetic track in one operation.

With a standard screw driver anyone can readily install the attachment, with its unique supporting bracket and clamping device, onto a sound projector in but a few seconds.

Since film sound translations are made at the mission headquarters, the attachment is supplied both for recording and playback; whereas only playback systems are supplied to the mission stations, thereby reducing the cost of the system and eliminating the possibility of accidentally erasing the translated sound track.

The record-playback system consists of a conventional vacuum tube preamplifier with a magnetic head-matching transformer, record amplifier, bias and erase oscillator, and an electric eye for monitoring. The playback output is arranged to operate through the microphone input jack of the projector's amplifier or through an external public address amplifying system.

The playback system for mission stations consists of a three stage grounded-emitter, low-noise transistor preamplifier, Fig. 4. The first stage serves as an impedance matching device, thereby eliminating the matching transformer, whereas the others are used for preamplification and equalization. The output is controlled by a volume control with sufficient level to operate any older type of projector amplifier as well as the later models.

A miniature ac power supply furnishes the voltages for the transistor preamplifier. Both units are sealed against moisture in a small metal container. They are equipped with a volume control as well as a neon pilot light to indicate power conditions. To prevent current "runaways" in the transistor stages, the heat dissipation in the power transformer is minimized.

Such a magnetic attachment has evident domestic applications. For example, with this attachment and a separate power amplifier and loudspeaker, binaural playback is obtainable. The optical sound system with its loudspeaker,

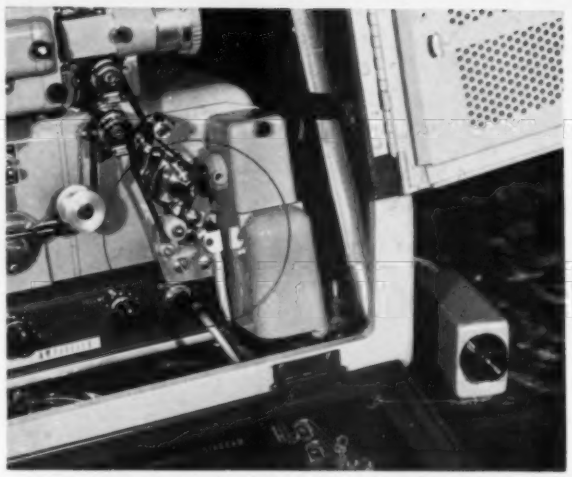

FIG. 3. Playback attachment installed on a Bell and Howell 385 16mm sound projector. The transistor preamplifier is shown at the extreme right.

serves as one channel; the magnetic attachment and additional amplifier serves as a second.

2. Tape Recorder Control Attachment

Another need of overseas audio-visual personnel has been a simplified method for automatically synchronizing recorded dialogue with a projected or non-projected (mechanically operated) still picture. (The use of high gain amplifiers, sensitized relays, special playback heads is not practical because of the limited number of technical men available for servicing.) To meet this need, the author recently

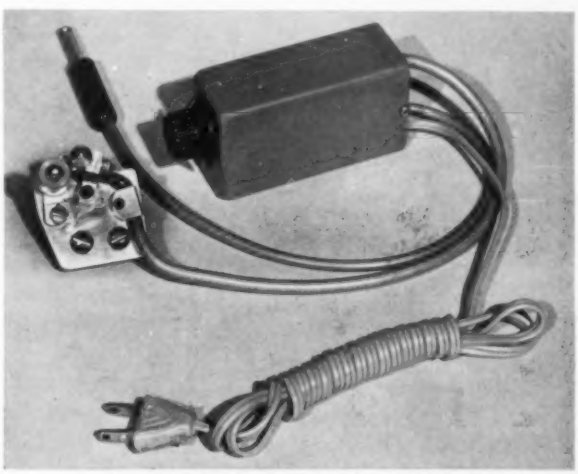

FIG. 4. Complete Bell and Howell attachment kit, showing mounting bracket, interconnecting cables, and 3 stage transistor preamplifier.

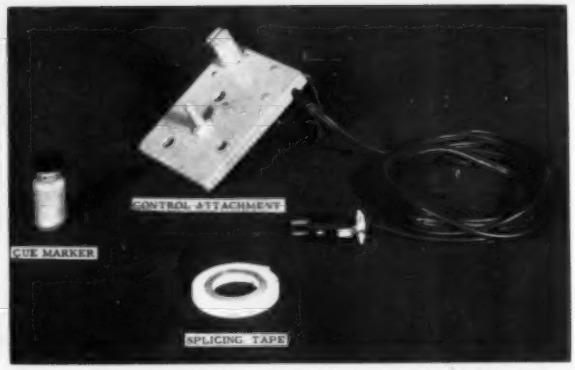

FIG. 5. Tape Recorder Control attachment shown with mounting bracket and cable.

designed and perfected a tape recorder control attachment.

This attachment, Fig. 5, with its unique, rust-proof, self-adjusting clamping bracket can be easily installed. No tools of any kind are required to slide the simplified molded plastic attachment on the side of any portable tape recorder. With a cued tape fed into the guiding detail, the device is immediately ready for use, Fig. 6. It operates on a simplified closed circuit principle. A metallized cue patch can be conveniently applied to the base side of any tape at the completion of each narration. This cue patch serves to send an electrical impulse to any remote-controlled picture changing device thereby assuring synchronization of picture and narration (or desired sound effects).

The attachment also accommodates tape repeaters for continuous operation. Slides or filmstrips can thus be operated synchronously with a narrated commentary.

3. Audio-Visual Mobile Unit

With a number of audio-visual mobile units now in operation in various countries, we have gained much experience relative to equipment setup in order to (1) best secure it against vehicle shocks and to (2) adapt it better for use with outdoor crowds. (The curiosity of audiences in the details of equipment operation tends to detract from the presentation of the message if the equipment is operated outside the vehicle.)

We shall describe a typical mobile unit which was designed for use in Kenya, Africa. This unit is free from unnecessary noise because an external auxiliary generator has been eliminated. The necessary equipment has been assembled in the most convenient, useful, and reliable manner possible to assist the mission worker in presenting an effective message under various conditions normally encountered in "the field".

Functions

The audio-visual equipment in this mobile unit was selected, arranged, and installed primarily to perform one or more of the following functions (with a minimum of inter-connecting cords):

A. A complete 30-watt *Public Address System*, with a built-in mixing arrangement to allow simultaneous mixing of:
   2—low impedance microphones
   1—three-speed phonograph
   1—tape recorder playback

B. *Tape record* (on tape recorder) through the public address system all sounds being heard by the listening audience.

C. *Project a 16mm silent or optical sound film* to an audience on a $7\frac{1}{2}' \times 10'$ screen.

D. *Project a 16mm magnetic sound film* on a $7\frac{1}{2}' \times 10'$ screen.

E. *Project (500 watts) a 35mm single or double frame filmstrip* or $2'' \times 2''$ slides on a $7\frac{1}{2}' \times 10'$ screen.

F. *Record outside sound effects on the 16mm magnetic sound track.*

G. *Operate up to 900 watts of flood lights* (6—150 watts each).

Description

A. *Truck*, Figs. 7 and 8.

The vehicle selected to transport and house the audio-visual equipment consists of a 1955 model, six-cylinder, half-ton Chevrolet, two-toned panel truck, having a heavy duty clutch, four-speed transmission, heavy duty tubeless tires and a two-quart capacity oil filter. The underside of the body is undercoated to retard rusting

This vehicle was chosen because of gasoline economy; also because of a 12-volt electrical system which conveniently and efficiently generates all the necessary electrical power required to operate its self-contained, audio-visual equipment.

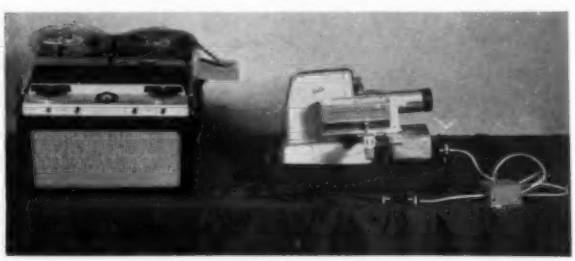

FIG. 6. Tape Recorder Control attachment installed on Pentron recorder. The tape is fed from a conventional reel to operate a standard slide projector equipped with an Airequipt slide changer and remote control motor. An interconnecting relay is used to carry the excess current required by the motor.

FIG. 7. Outside view of audio-visual mobile unit designed for use in Kenya.

B. *Shelf*, Fig. 9.

A plywood shelf is installed (covered with a rubber mat top with polished aluminum trimmings on all edges) on the opposite side of the driver's seat, running approximately the full length of the body compartment and extending some 22 inches from the side to the center. It is supported on the floor by 1¼-inch angle iron supports to a height of 26 inches.

Polarized electrical receptacles are arranged above and to the rear of the shelf to allow the Pentron tape recorder, Bogen amplifying system (with phonograph), the Ampro 16mm sound motion projector, and the 35mm projector to be operated conveniently by the operator as he is seated.

A small, folding shelf is arranged at the rear side of the long, running shelf, allowing it to be raised and locked in position to support the 35mm Viewlex projector thus permitting projection out of the rear doorway of the truck. The shelf is folded down out of the way when not in use.

C. *Electrical Equipment System*

The truck is arranged to generate all of its electrical power from the vehicle's engine, running at a fast, idling speed (approximately 500 rpm). The generated voltage is automatically regulated by means of a heavy duty voltage regulator.

FIG. 9. Interior view of mobile unit. The shelf which supports the tape recorder, the amplifier with phonograph, and the film projector is shown to the left of the author.

FIG. 8. Audio-visual mobile unit set up. The 2 University loudspeakers appear at the left; the floodlight stand at the right.

The conventional 12-volt, standard generator has been removed and replaced with a heavy duty Leece-Neville model 5062-GA6, 3-phase 14-volt alternator, driven from the engine by means of the fan belt with a dual pulley and belt. This alternator (having no heavy current brushes to maintain and replace) serves two purposes:

1. To generate normal and booster rate charging current for charging the vehicle's storage battery.
2. To generate all the necessary current required to operate the audio-visual equipment.

Charging Current

The output of the alternator (14 volts, 3 phase) is connected to a 3-phase, heavy duty selenium rectifier, mounted behind the left of the radiator in the engine compartment. The rectifier supplies an output of 12 volts. The auxiliary ammeter, mounted on the dash board, serves to indicate the flow of this current to the vehicle's storage battery. The charging rate to the battery is self-regulated (in relation to that demanded by the storage battery) by means of the voltage regulator mounted at the front right of the engine.

Note: The conventional voltage regulator mounted at the rear of the engine is disconnected.

Equipment Current

The alternator (cabled by means of a 3-conductor #4 gauge stranded cable to a 3-phase specially designed heavy duty step-up transformer) steps up the 14-volt alternator current to 110 volts.

A 60 amp 2-gang circuit breaker, wired between the alternator and the primary winding of the step-up transformer, serves to give protection against overloads and short circuit conditions. It also acts as a main switch to turn off all of the audio-visual equipment power when required.

Because of the varying frequency of the alternator output (from 40 to more than 160 cycles per second, which is determined by the speed of the engine at which the alternator is being operated) this 110-volt output is unable to operate properly the tape recorder motor drive, phonograph turntable motor and the 35 mm blower motor. A heavy duty 3-phase selenium rectifier connected to the output of this transformer converts the alternating current to 115-volt direct current at 1400 watts. The transformer and rectifier are mounted in the ventilated and protected metal covering under the shelf opposite the driver's seat and is secured to the floor.

Inverter

An ATR model 110T-HSH inverter is connected to the 110 v dc source by means of a dc receptacle which is mounted at the rear side of the transformer rectifier metal protective cover. The output of the inverted 110 v 60c ac is wired to various receptacles throughout the vehicle to operate all frequency-sensitive equipment. Further circuit protection is made possible by means of two independent circuit breakers, having a rating of 15 amps each. One is for the inverter and the other for the complete dc load. These are located at the center of the right side door.

Wiring

A selective switching system, consisting of 3 toggle switches permanently wired with approved wire and metal boxes, has all switches mounted above the shelf and made accessible to the operator. The purpose of this is to prevent unnecessary overloads on the generating system as one equipment load is switched to another equipment load and the unwanted or unused load is not turned off. This arrangement also allows the operator to co-ordinate changeovers promptly and with smoothness of changes.

Receptacles

There are three receptacles mounted at the inside location of the rear doorway and one above and one below the shelf. Each receptacle is polarized (each requiring a different type of plug) to prevent the accidental connection of the wrong equipment to a given power source thus causing damage. They are as follows:

1. "P.A. System" (2—5 pin jacks)
2. "Lights"—115 volts dc (2-pole twist-lock receptacle)
3. "16mm Projector Speaker" (2-pole phone jack)
4. "110-volt 60 cycles" (standard U. S. A. 2-pole receptacle)
5. 35mm projector (6-pin Jones plug)

Interior Lighting

A U. S. A. standard pull chain socket is provided to accommodate a light bulb in order to light the equipment and monitoring panel. This is mounted on the ceiling and is equipped with a 25-watt 115-volt lamp. A larger wattage may be used but should not exceed 50 watts.

Audio Monitoring

At the right side of the vehicle, above the equipment shelf, an audio monitoring control panel is installed. It incorporates a 4-inch sound level meter, two lever-type switches, 2 volume controls wired to the output of the 16mm sound projector amplifier and the Bogen public address system amplifier, the University BLC loudspeaker line, the 16mm projector loudspeaker line, and a monitor 6" × 9" oval-type loud speaker. The latter is installed at the rear side of the plywood supply cabinet.

With this audio monitoring control arrangement conveniently before him, the seated operator can visually check the sound output (on the sound level meter) to the 16mm sound projector speaker by operating the

(*Continued on page 31*)

Mechanical Crossover Characteristics In Dual Diaphragm Loudspeakers *

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This paper points out the importance of mechanical and acoustical crossovers in loudspeaker systems. It discusses the role of diaphragm shape and material in controlling the mechanical crossover characteristics. The principles set forth are applied to an analysis of the behavior of a typical commercial dual-diaphragm type loudspeaker, in which mechanical separation of low and high frequencies is obtained by the use of apex-mounted diffuser-type radiating elements. Frequency response curves were taken for conical and curvilinear diaphragms in which the compliances at the apex were modified, and the effect of the auxiliary diaphragm was observed. Graphs illustrating these results are presented.

INTRODUCTION

IN THE EARLY days of the electrical reproduction of sound, we were quite satisfied with a single loudspeaker as the source of the reproduced sound. Through the years, sound reproduction has gradually and consistently improved. With the advent of today's high fidelity techniques, it has become desirable to reproduce sound by separating the total sound into narrow bands in order to make the reproduction of those bands more faithful, cleaner and more easily controlled. As a result of this philosophy of breaking up the reproduced spectrum into areas which may be individually controlled, we have developed the present concept and the techniques of multi-speaker systems. It is not our intention at this time to go into the many benefits of such multi-speaker operation for they have been fully covered before, and will no doubt be covered again and again in the literature. We are concerned here with a particular manner of dividing the total frequency spectrum which is to be reproduced into bands in which the separation is to be made by allowing a speaker with a single voice coil to drive two separate diaphragms.

ACOUSTICAL AND MECHANICAL CROSSOVERS

Now while it is true that in multi-speaker systems, the electrical crossover network plays an exceedingly important part in distributing the *electrical energy* and in the corresponding production of the acoustical energy, there are, however, other types of crossovers such as mechanical and acoustical which have not received the attention that they deserve.

The electrical network in a multi-speaker system serves one specific purpose, that of receiving the entire electrical spectrum fed to it from the driving amplifier and then breaking up the spectrum into as many bands of electrical energy as required by the system. By so doing, it is possible to allocate each band to that speaker which is best suited for its reproduction. It is then possible to employ highly efficient speakers designed for those particular bands, with consequent conservation of electrical energy. However, it is not nearly enough to know that electrical energy has been properly distributed among the various loudspeakers of a system; it is of equal importance to know how the various speakers themselves reproduce the sound from the electrical signal. The factors governing this correlation between the electrical input as seen by the speakers, and their actual acoustical output, was covered by the writer in a previous paper[1] which discussed multi-impedance. multi-crossover networks, so designed to form compatible systems with various types of loudspeakers. It was possible then to give but a few applications of crossovers other than electrical. However, it was indicated that the *acoustical* roll-off characteristics of the speakers themselves were as important as the electrical network in determining the crossover characteristics of the system as a whole. It was

* This paper was presented at the Seventh Annual Convention of the Audio Engineering Society, New York, October 15, 1955.

† Engineering Manager

[1] A. B. Cohen, *J. Audio Eng. Soc.*, 3, 40 (Jan. 1955).

shown that a 12 db per octave network applied to a cone speaker in a large baffle would roll off the low frequency end of that speaker less than a 6 db per octave network applied to a compression-driven exponential horn, where the horn had its own natural cut-off governed by its rate of expansion. In other words, a less steep network on a horn which has an inherent low frequency cut-off may produce a steeper attenuation characteristic than an originally sharp network applied to a loudspeaker which lacks a natural roll-off. We see, therefore, that we cannot be entirely sure of the true crossover characteristics of a system if we consider only those factors which deal with the electrical crossover characteristics of the network that feeds the system. Thus the *combined* system has a roll-off that is a function not only of its electrical constants but of its acoustical ones as well. Furthermore, crossover characteristics may be controlled by mechanical methods as well as by electrical and acoustical. It is the purpose of the present paper to discuss and to illustrate by actual measurement those properties of loudspeaker construction that provide mechanical crossovers in loudspeakers of the dual diaphragm type which are driven by a single voice coil.

We should regard the word "mechanical" in loudspeaker terminology with as much respect as we do the terms "electrical" and "acoustical," for, in the last analysis, the performance of a loudspeaker depends more upon its mechanical than upon its electrical characteristics. A previous paper by the writer entitled "Mechanics of Good Loudspeaker Design"[2] discussed those mechanical factors which determine the performance of a loudspeaker. One illustration from that paper will set off the discussion on the actual mechanics of loudspeaker reproduction: the manner in which the mechanical construction of the cone affects the total performance of the speaker; in turn, this will lead to a consideration of mechanical crossover circuits.

EFFECT OF CONE GEOMETRY

In Fig. 1 we see how the shape of the diaphragm determines its mechanical stability. The flat diaphragm on the left would be an extremely unstable platform upon which the leprechaun may do his dancing. This flat diaphragm, suspended at its ends, represents a sort of suspended, flexible, jumping board that goes up and down as our little man jumps up and down on it. If this diaphragm were to be driven at its center by a voice coil as in Fig. 1c, the motion of the diaphragm would not be that of a solid piston, but would tend to bow in and out as the voice coil responded to the current driving it.

In contrast, however, the physical structure shown in Fig. 1b clearly indicates that our little dancing man would have quite a bit of difficulty in deforming this diaphragm. In

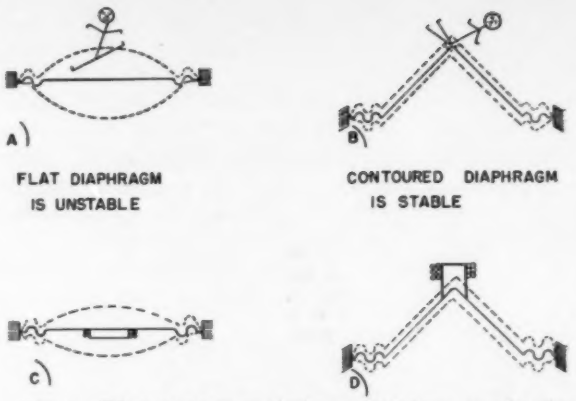


FIG. 1. Effect of shape on diaphragm stability; A—flat diaphragm, B—conical diaphragm, C—(A) with voice coil, D—(B) with voice coil.

other words, a diaphragm of this conical shape has considerable mechanical stability, and, as shown in Fig. 1d, if a voice coil were to drive such a diaphragm, it would move more rigidly as a piston than would the flat diaphragm.

Now, although these two illustrations are extremely simplified, they exemplify to a great extent the action of cone speaker diaphragms insofar as they are affected by the geometry of their shape. In between these two extremes many shapes of diaphragms have been designed to intentionally perform, as the flat diaphragm in Figs. 1a and 1c, or, as the conical diaphragm in Figs. 1b and 1d. The design chosen depends entirely upon what is desired in the way of performance from the loudspeaker.

EFFECT OF CONE MATERIAL

It is usually the case to choose a conical diaphragm, as in Fig. 2a, where a woofer type of loudspeaker is desired so that the diaphragm itself will move as a whole, i.e., as a piston, when driven by the voice coil. However, where a wide range speaker is required, the diaphragm may take a curvilinear shape as shown in Fig. 2b. We may use Fig. 2b as a starting point from which to analyze the diaphragm action further. It may be considered as (1) a single diaphragm that will move as a rigid piston for low frequencies, and (2) a multi-diaphragm loudspeaker in the sense that it tends to separate into distinct zones of action at high frequencies, depending upon several factors such as the applied frequency, diaphragm shape, and the diaphragm material. It is commonly realized that the high frequency reproduction from a diaphragm is mostly obtained from the apex region, and that the extent of this region is considerably affected by the shape of the diaphragm and its material. In a very general sense, the distribution of the compliances along the body of the diaphragm will deter-

[2] A. B. Cohen, *J. Audio Eng. Soc.*, **2**, 176 (July 1954).

mine the degree to which the high frequency driving force applied to the apex of the cone will be transmitted to the diaphragm as a whole. Since the diaphragm consists of a fibrous material, it may be considered made up of small rigid sections joined to each other through small flexible segments called compliances, or, little springs, Fig. 2c. Now as the innermost section of the diaphragm tends to move forward, it will transmit its motion to the adjacent section only to the extent that the stiffness of the connecting compliance will permit. And so, as we pass from section to section, there will be a gradual roll-off of energy transferred from the apex of the diaphragm to the outer sections of the diaphragm. If the compliant coupling is very stiff, then it may be expected that high frequency transmission would be obtained to a considerable degree out towards the rim of the cone. Thus by judicious choice of the fabric or stock out of which the cone is made, and by the addition of lumped compliances to the cone, we may control the actual distribution of the high frequency energy transmitted by various sections of the diaphragm. We may thus consider a diaphragm of this kind to behave effectively as a multi-diaphragm loudspeaker in a very rigorous and strict sense. There is a smooth transition between the various sections of the diaphragm, and I wish at this point to differentiate between this type of diaphragm and the multiple diaphragm assembly more commonly recognized as employing mechanical crossovers. This distinction will be made after we have discussed how the *shape* of the diaphragm, as well as the diaphragm pulp stock, affects the transmission of high frequencies.

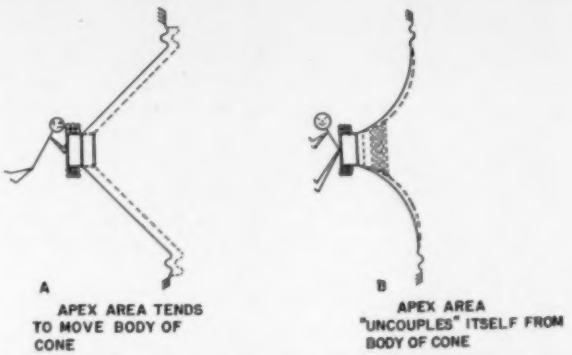


FIG. 3. Illustration of cone reaction to voice coil motion; A—conical diaphragm, B—curvilinear diaphragm. The curvilinear shape shows greater compliance at high frequencies so that "uncoupling" takes place.

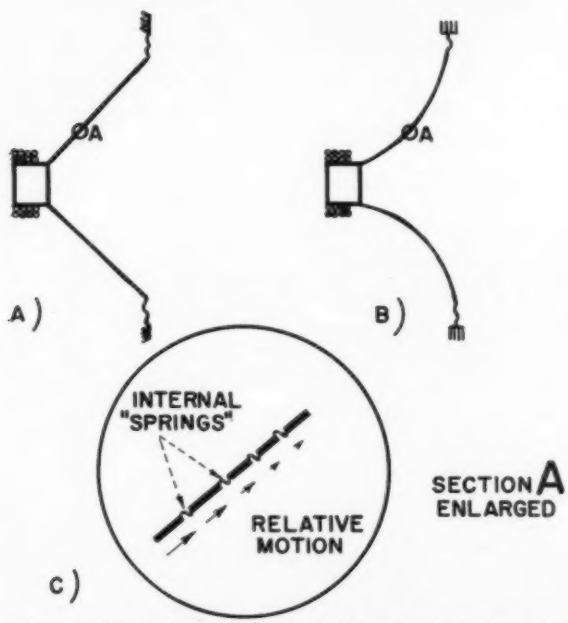


FIG. 2. Effect of material upon diaphragm motion; A—conical diaphragm, B—curvilinear diaphragm, C—section of diaphragm showing "internal" compliances.

ROLE OF DIAPHRAGM SHAPE AND MATERIAL ON HF BEHAVIOR

In Fig. 3, we show how the mechanical stability of cones with different cross-sections determines their acoustic behavior. The conical cone, Fig. 3a, will obviously move as a piston when pushed forward at its apex area. However, the curvilinear cone shown in Fig. 3b, being already bent into an arc, would have a tendency to bend even more in the direction of its motion when it is energized at its apex. Therefore, depending upon the degree of curvature of this cone, it will be obvious that the diaphragm will separate itself into different areas of operation. This large bend is as much a "spring" as are the small internal compliances of the cone material. Now if the bend of the diaphragm is such as to present a small spring load to the driving force, then the diaphragm will move as a whole. This is usually the case for low frequencies. For high frequencies, however, the bend represents a considerably higher compliance, and the apex of the diaphragm will tend to separate from the main body of the diaphragm, as shown in Fig. 3b. There will be essentially two different areas of operation as indicated by the shaded section. The small apex area will reproduce those higher order frequencies for which the apex of the diaphragm becomes uncoupled from the main body of the diaphragm. For the low frequencies the outer areas will move along with the central areas. Therefore, by choosing the proper shape and curvature of the diaphragm, we may in some measure control the high frequency repro-

FIG. 4. Typical dual-diaphragm loudspeaker construction.

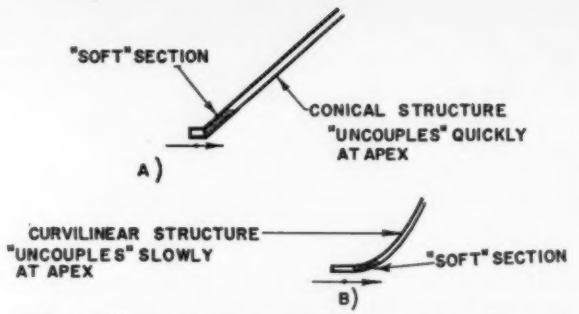


FIG. 5. Effect of adding an extremely compliant section to the apex of the cone. The "uncoupling" at the immediate apex area is shown to be greater with (A) the conical shape than with (B) the curvilinear, where the angle of the cone is more directly in line with the driving force.

duction characteristic of the loudspeaker. Quickly summarizing then, how the loudspeaker behaves at low and high frequencies depends upon the diaphragm *shape* and the diaphragm *stock*. These are the determining factors as to the gradual separation of the various sections of the diaphragm for the reproduction of low frequencies and high frequencies.

TYPICAL DUAL DIAPHRAGM SPEAKER

These factors just discussed are now directly applicable to a discussion of actual dual diaphragm types of loudspeakers. A typical assembly is shown in Fig. 4. In this structure, the large diaphragm serves as the low frequency reproducer, and the high frequency diaphragm is mounted at its apex in a fashion which we will shortly discuss. Inherent in the design of such loudspeakers, there exist certain specific characteristics which make these two diaphragms *acoustically distinct* from each other even though they are mechanically fastened to the same voice coil. By properly proportioning the mechanical constants of each one, it is possible to obtain woofer performance from the main diaphragm and treble performance from the other; each acting more or less independently of the other. In

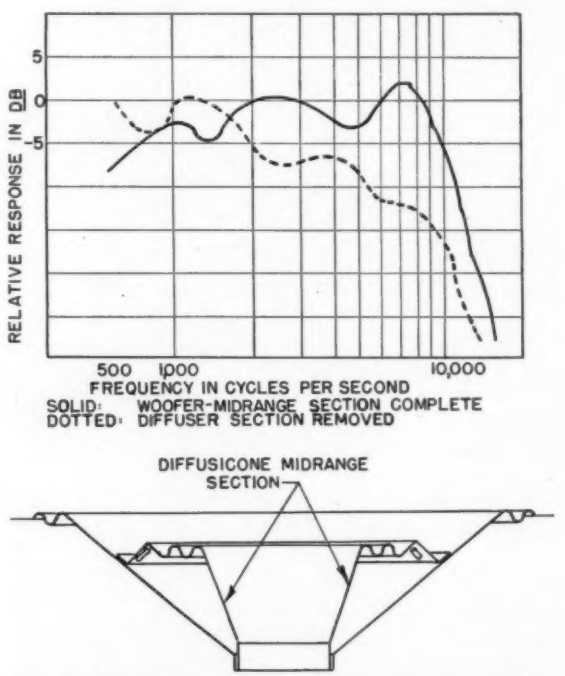
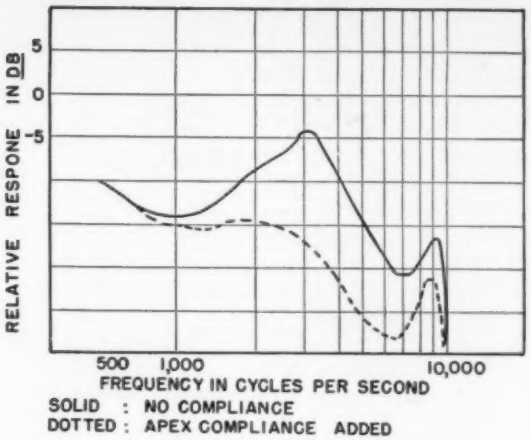


FIG. 6. Generalized response curves of woofer mid-range section of experimental University Model 315 speaker before and after removal of diffuser mid-range section indicating added response in the treble region by the addition of the diffuser.



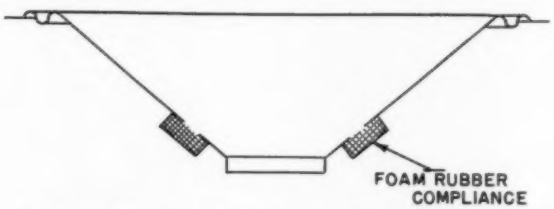


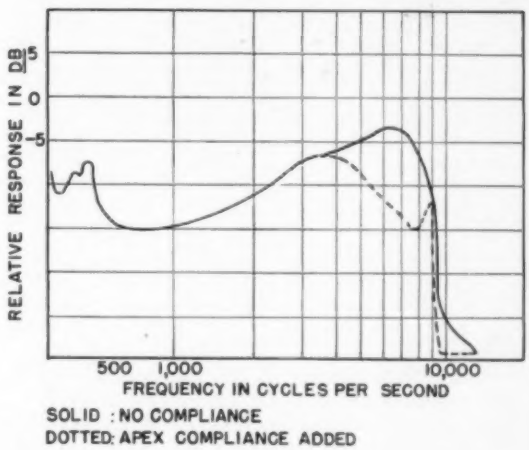
FIG. 7A. Response curves of a conical diaphragm showing the loss of high frequencies when apex area of cone is decoupled.

fact, our demonstration will show that by the addition of the second auxiliary diaphragm to the woofer diaphragm in the manner shown the performance of the speaker is actually extended considerably beyond its original single-cone behavior. It should be emphasized that what occurs is not merely the redistribution of sound energy, but an actual extension of the frequency response of the speaker. Now the addition of extra energy to the high frequency performance, and the degree to which the separation of the frequency responsive function between the two diaphragms takes place, is determined by the mechanical design of the two diaphragms, and therefore, we term this type of a structure a dual diaphragm loudspeaker with mechanical crossover.

From the previous discussion of a single diaphragm, it is apparent that for maximum radiation from a single diaphragm, we should make the diaphragm as stiff as possible so that it will not break up into separate modes of vibration. Thus, in accordance with the discussion of the structures in Fig. 3, the auxiliary high frequency diaphragm in Fig. 4 is designed as a conical element so that there will be minimum flexing of its parts. By giving it this shape and keeping it small the high frequency diaphragm will perform as a piston within the range of its application. As for the low frequency diaphragm, it need now reproduce only the low frequencies; it has been relieved of the necessity of reproducing the high frequencies.

Now how can we prevent the high frequencies from being absorbed by the main portion of the woofer diaphragm itself? This can be accomplished as explained before by so choosing the material or stock from which the woofer cone is made that the cone quickly uncouples itself *at the apex* before any appreciable amount of high frequency energy is absorbed by the woofer cone. Figure 5a shows such a construction.

It will also be observed that if the shape of this cone is such that it quickly bends away from the application of the force, the body of the cone will tend to move less with that force than if the cone breaks away gradually as in Fig. 5b. In the latter situation, the curvilinear, it will be seen that the force imparted by the driving voice coil will



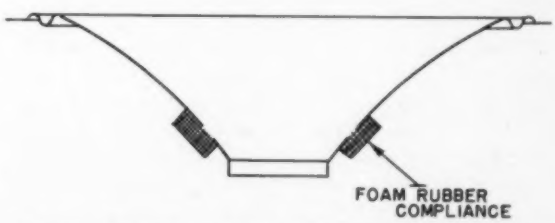
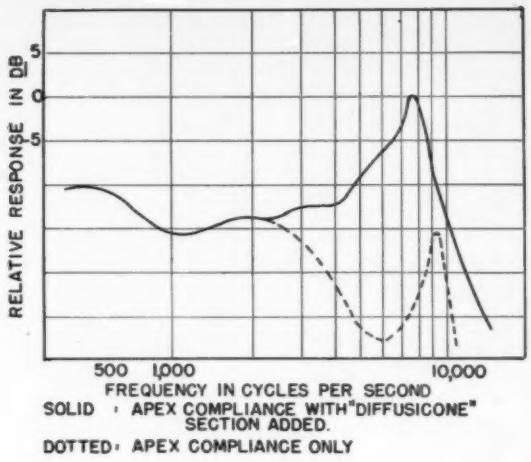


FIG. 7B. Response curves of a curvilinear diaphragm showing loss of high frequency response when apex area of cone is decoupled. Note much less attenuation of highs as compared with conical (Fig. 7A).



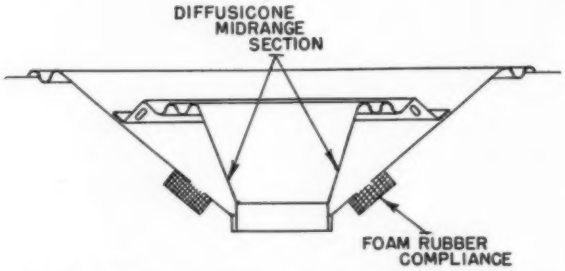


FIG. 8A. Response curves showing increased treble response to a conical diaphragm decoupled at its apex area, but with Diffusicone mid-range section added.

still tend to push edgewise into the body of the cone itself, and try to move it, whereas, in Fig. 5a, the conical, the force will pivot away from the face of the cone and will permit the cone to remain more or less stationary. Therefore, it is apparent why a conical diaphragm may often be preferred for the woofer in two-way systems.

In summary, then, among the requirements for the independent dual action of the multi-diaphragm speaker, we have (1) the shape of the woofer diaphragm should preferably be conical and of very compliant material such that the body of the cone remains as immobile as possible right down to the apex for those frequencies to be reproduced by the separate auxiliary high frequency diaphragm, and (2) the latter should be of such stock as will make it as rigid, stable, but still as light as possible, for maximum high frequency generation.

PERFORMANCE CHARACTERISTICS

Now, before we describe the actual performance of this sort of a device, it is of importance to realize that besides this mechanical crossover characteristic, there is also an important inherent acoustical crossover. It is well-known in the acoustic art that the radiation capabilities of a diaphragm depend upon its diameter. If the area of a diaphragm is small, it will reproduce low frequencies poorly. Furthermore, if the diaphragm is shallow, it will have better wide angle response than when it is deep. Thus in the design of a dual diaphragm loudspeaker of this sort, we find that the *low* frequency performance of this auxiliary high frequency diaphragm is directly related to its effective piston diameter and that its directional characteristics are a function of the angle of the diaphragm. Therefore, this auxiliary diaphragm, being relatively small in diameter, possesses an acoustical roll-off for low frequencies, even though it is being driven by the same voice coil which drives the larger low frequency diaphragm. In this sense

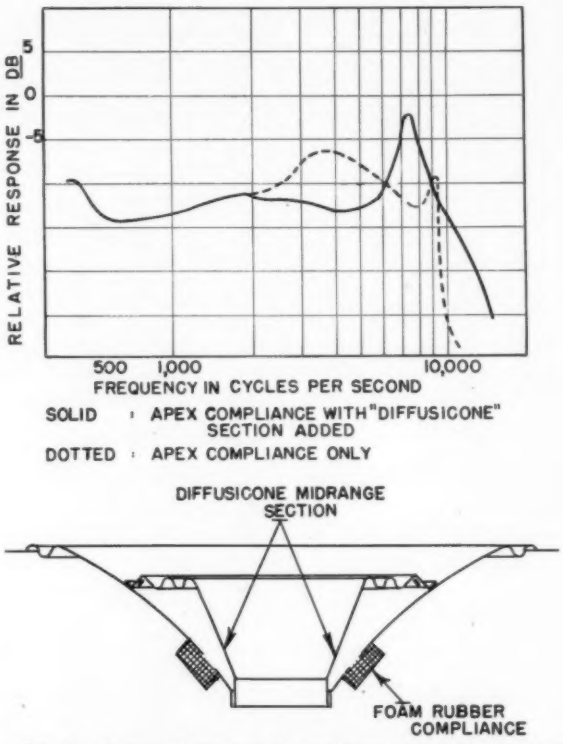


FIG. 8B. Curves of response of curvilinear cone with apex area decoupled and Diffusicone mid-range section added. Note decreased woofer high frequency attenuation and poorer treble response as compared with conical diaphragm (Fig. 8A).

then, we have a combined mechanical and acoustical crossover device.

With these introductory remarks concerning the mechanical characteristics of the dual diaphragm construction and the brief details governing the choice of these characteristics, let us go on to the actual curves which describe the performance of such a unit.[3]

The curves shown in Fig. 6 compare the performance of a woofer loudspeaker with and without a Diffusicone section. They clearly indicate that the original loudspeaker woofer section had poor high frequency response above 4000 cps, but that by the addition of the Diffusicone diaphragm there has been a decided improvement of response between 4000 cps and 10,000 cps.

In Figs. 7a and 7b are shown similar curves taken of two experimental cones, one conical in shape and the other curvilinear, with and without extremely compliant foam rubber sections at the apex of the cone. These curves illustrate the degree to which the high frequency performance of the woofer cone may be deteriorated by the shape of the cone and by the application of compliances in critical areas. Figure 7a shows a conical cone, with and without the compliant area at the apex of the cone. Note the very sharp loss of high frequencies when the main body of the cone was uncoupled from the main driving force by means of the foam rubber joint. Figure 7b shows a curvilinear cone with the same compliant modifications. Note first that the high frequency response of the curvilinear cone was superior to the conical, and second, observe that the loss for the high frequencies due to the apex uncoupling was far less for the curvilinear than for the conical. This is indicative of the effect that the shape has on the high frequency performance. For the same weight of cone, the same thickness and the same apex compliance, the apex shape in the curvilinear case was still such that fairly good high frequency transmission into the body of the cone took place, whereas for the conical, there was almost complete loss of high frequency transmission.

In Fig. 8a are shown two curves illustrative of the effect of the mechanical crossovers in the cases of a conical and of a curvilinear cone, both with the high degree of compliance at the apex, but with an auxiliary diaphragm mounted at the apex. It will be seen that the conical woofer cone has excellent high frequency roll-off characteristics which permit the Diffusicone element to pick up the high end as a separate direct radiator, whereas for the curvilinear cone, this effect is not nearly so pronounced.

CONCLUSION

In conclusion we may say that these experimentally run curves summarize the fact that mechanical crossovers in loudspeakers may be engineered to provide actual separation of frequency bands between the bass section and the treble section so that even though both diaphragms are driven by the same voice coil, dual band performance results.

EDITOR'S NOTE:

The reader who is interested in an analysis of this type of loudspeaker (and others) by means of the electrical-mechanical-acoustical analogies method is referred to the following literature:

1. H. F. Olson, *J. Acoust. Soc. Am.*, **10**, 305 (1939).
2. H. F. Olson, *Acoustical Engineering*, 3rd Ed., (D. Van Nostrand Co., Inc., Princeton, 1957), p. 141.
3. L. L. Beranek, *Acoustics*, (McGraw-Hill Book Co., New York, 1954), p. 201.

[3] The curves which follow were obtained in the hall at the Hotel New Yorker where this paper was presented. A photograph of the apparatus appears on page 133 of the July 1956 issue. [Ed.]

Reverberation Chambers for Broadcasting and Recording Studios*

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This paper discusses the design of reverberation chambers for use in sound recording studios. Such factors as the optimal ratio for height-width-length for various room sizes, the variation of reverberation time with room volume for enclosures having such preferred dimensions, and the effect of wall construction using materials with various sound absorption coefficients are considered and illustrated graphically. Equations for estimating noise infiltration and the effect of small openings are given. It is indicated that the minimum dimensions required to achieve satisfactory results for adding reverberation to recorded speech and music should be of the order of $\lambda/2$ at the lowest frequency of interest, and that the minimum room volume should exceed 1000 cubic feet. A summary of the factors which must be considered in the construction of such chambers is offered in conclusion.

INTRODUCTION

THE TREND during the last few years in recording studio design has been toward enclosures of shorter reverberation periods (or times) in the 500 to 1000 cycle frequency region. This is due to the increasing use of so-called reverberation chambers which lend a note of flexibility to the studio and which allow the accommodation of a wider variety of programs, as well as a wider variation in orchestra size than would otherwise be possible. Actually, studios with short reverberation periods do more than that; they allow the use of a larger band in the enclosure, because acoustic separation and isolation between microphones can be obtained more readily in a dead than in a live space. This separation adds to studio flexibility and offers greater latitude in defining sections of the orchestra.

Some descriptive articles on reverberation chambers,[1] chiefly by the writer, have appeared in motion picture journals, but little has been published in audio technical journals. It is the purpose of the following to discuss such chambers in some detail.

* Presented at the West Coast Convention of the Audio Engineering Society, Los Angeles, California, February 7, 1957. Manuscript received March 26, 1957.

[1] The writer would like to note that he takes exception to the use of the term "echo chamber" in place of the term "reverberation chamber." An echo is a distinctly audible pulse or reflection, whereas reverberation consists of reflections so diffused that no distinct single reflection is audible. Indeed, the writer takes great pains to keep echoes out of the reverberation chambers that he is called upon to design (and shudders when someone compliments him on one or the other "echo chamber" associated with his name).

PREFERRED ROOM DIMENSIONS

Consideration is often given in recording studio design to employ such ratios of height to width to length of a room, as will avoid coincidental reinforcement of the normal modes of vibration.[2] It is doubtful, however, whether such considerations are of much merit from a practical point of view. The reason for this is that these rooms in practice seldom have the true shape of a rectangular parallelepiped, for which the normal mode frequency distribution is well known. Generally, the studio contains a number of objects in the enclosure—instruments, performers, furniture, etc.—which make the distribution of modes practically impossible to calculate. The condition is made even worse by the abundant use of acoustic materials which similarly exert a pronounced influence on this distribution.

For reverberation chambers, however, a consideration of such preferred room dimension ratios carries considerably more merit, because reverberation chambers are generally empty, except for a small microphone and loudspeaker in the room. Moreover, reverberation chambers are "live" so that the wall material has but little effect in altering the theoretical results of the mode distribution.

There is no one single ratio of height to width to length which is vastly superior to others to effect a uniform mode distribution. The most popular are:[3]

[2] The term "normal modes of vibration" refers to the characteristic resonant frequencies of an enclosure. These are completely determined by its geometry. [Ed.]

[3] Cf. J. E. Volkmann, *J. Acoust. Soc. Am.*, 13, 234 (1942). [Ed.]

$$1 : 1.26 : 1.58 = 1 : \sqrt[3]{2} : \sqrt[3]{4}$$
$$1 : 1.58 : 2.52 = 1 : \sqrt[3]{4} : \sqrt[3]{16}$$
and $$1 : 1.58 : 3.17 = 1 : \sqrt[3]{4} : \sqrt[3]{32}.$$

The reverberation time T of a room is at room temperature given by

$$T = 0.049\, V/aS \text{ seconds},$$

where V is the room volume in cu. ft., a is the absorption coefficient of the walls, ceiling, and the floor (all assumed of the same material), and S is the total interior surface area in sq. ft.

In the case where the ratio of the dimensions is 1 : 1.26 : 1.58, the equation for T reduces to

$$T = 0.0103\, H/a$$

where H is the ceiling height. As an example, a room 10′ high, 12.6′ wide, and 15.8′ long, finished in the interior with 0.5″ plaster whose absorption coefficient at 1000 cycles is $a = 0.03$ sabins, will have a reverberation time of

$$T = 0.0103 \times 10/0.03$$
$$= 3.44 \text{ sec.}$$

Note that doubling the volume of the chamber (which gives a room 12.6′ high, 15.9′ wide, and 20′ long) will increase the reverberation period only 26 percent. However, if the room can be treated with a material whose 1000 cycle absorption coefficient is only 0.015, the reverberation period will double. Similarly, the period can be doubled by doubling the ceiling height, which, of course, produces 8 times as great a volume (if the width and height of the chamber are proportionately increased, at the same time).

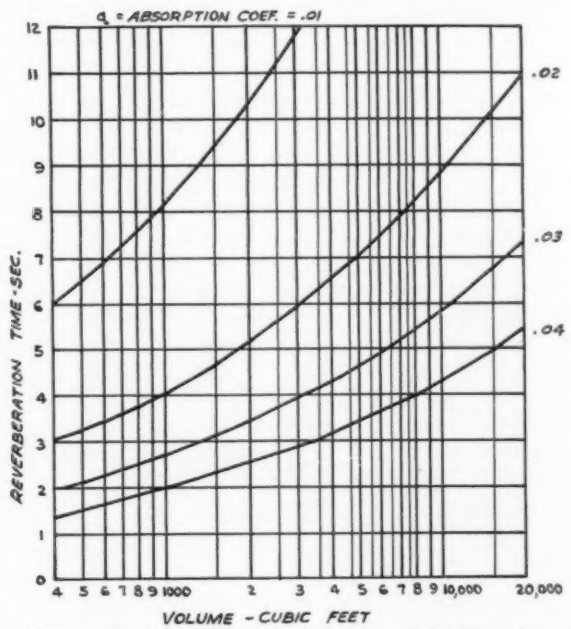

FIG. 1. Effect of enclosure volume upon reverberation time at 1 kc for 4 values of the absorption coefficient.

Figure 1 shows the variation in the 1000 cycle reverberation time of 1 : 1.26 : 1.58 parallelepipeds as a function of the room volume when wall materials of various absorption coefficients are employed. Figure 2 shows the variation of ceiling height, width, and length of room as a function of room volume when the dimension ratio is 1 : 1.26 : 1.58. For the addition of reverberation to music recordings made on tape or film, a reverberation time of 4 seconds is entirely adequate. This can be obtained with a room 9.6′ high, 12.1′ wide, and 15.2′ long, (1770 cubic feet) when its interior is finished with 1″ thick cement plaster having an absorption coefficient of 0.025. The reverberation period can be increased if poured concrete several inches thick is used, or if a 1″ thick cement plaster is applied against a brick wall. The reverberation period can be made still longer by treating the concrete (after thorough drying) with a sealer and then applying varnish.

There is still no uniformity in the opinion of the experts on whether such reverberation chambers should have the shape of a true parallelepiped or whether the walls should be angled or splayed so as to avoid the parallelisms existing between opposite walls. This writer inclines to the opinion that non-parallel walls are preferable. The reason for this is that loudspeakers in the reverberation chamber are usually not located in a wall surface, but stand in the room between parallel surfaces; in which case, undesirable echo effects can be heard particularly during the reproduction of staccato notes.

It has been suggested that more than one microphone be used in a reverberation chamber to avoid the recording of pronounced sound pressure peaks and dips, especially during prolonged passages. However, such an arrangement could make matters worse, since in the event each microphone is located at a pressure peak the recorded excess volume will be considerably greater than when a single microphone is used for pick-up. Similarly, the practice of rotating or swinging microphones to smooth out the recorded sound may produce frequency modulation and thereby introduce a flutter-like quality in the recorded sound. It is generally best to employ non-directional microphones in a reverberation chamber together with a small speaker, so as not to introduce excessive absorption in the enclosure. The volume of the reproduced sound should be kept at normal level, and the microphone should be located away from a wall.

Attempts to make the reverberation chamber in the shape of a tunnel so as to secure echo effects are generally unsatisfactory because not only does the tunnel have to be

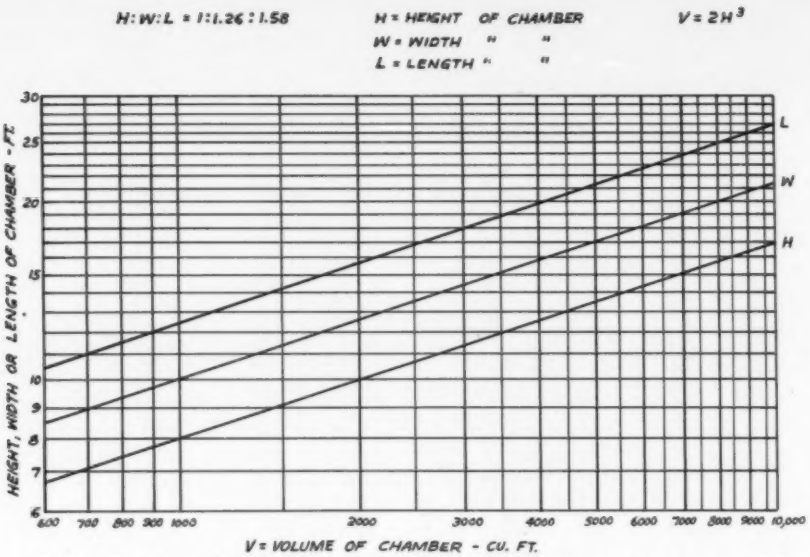

FIG. 2. Relation of chamber volume to height, width, and length when the chamber proportions are 1 : 1.26 : 1.58.

made rather long (at least 113 feet, in order to get 0.1 second delay) but also the restricted size of the tunnel produces undesirable transverse wave effects.

Figure 3 is a diagram of a more elaborate dual reverberation chamber,[4] constructed on the RKO and the Republic Studio lots. The aperture between the chambers can be controlled from the mixing console to achieve various sound effects; it functions as an acoustic high pass filter.

Delay networks, magnetic tape recordings, and other devices employed for achieving synthetic reverberation usually permit the recording of only the decay characteristic. No attempt is made to introduce the growth characteristic. However, by plotting the growth curves and the corresponding decay curves, we learn that this growth characteristic becomes rather important for live enclosures. For instance, in a room in which the reverberation time is four seconds, it may well take two seconds for the sound to reach a steady-state condition. Therefore when a prolonged tone burst is reproduced through a reverberation chamber, a slight increase in volume is heard before decay sets in. With delay networks and magnetic tape devices, however, such an increase in volume will not occur, rather, a "steady state" volume will be reached quickly; after which the sound will die away. For this reason, they result in a less "realistic" approach to the addition of reverberation to speech or music recorded in a relatively "dead" room.

[4] U. S. Patent No. 2,431,962.

EFFECT OF NOISE INFILTRATION

It is important in the construction of reverberation chambers to avoid the transmission of undesired sound from the outside. To illustrate the degree of noise infiltration through a small opening in a wall or through an insufficient door seal, consider a reverberation chamber 10′ high, 12.6′ wide, and 15.8′ long. Its total interior surface area, S, will be about 1000 sq. ft. Assume the wall, ceiling, and floor construction to be identical, say, 6″ thick concrete for which $\alpha = 0.01$. Then the total interior absorption, A $(= \alpha S)$, amounts to 10 sabins. If the transmission loss, TL, of the boundaries at a certain frequency is 60 db, the acoustic transmittivity, τ, given by,

$$\tau = \log^{-1}(-TL/10)$$

is then $$= \log^{-1}(-6) = 10^{-6}.$$

The total transmittance T will be

$$T = S\tau$$
$$= 10^3 \times 10^{-6} = 10^{-3}.$$

The noise insulation factor[5] NIF of the room will be

$$NIF = 10 \log (A/T)$$
$$= 10 \log (10/10^{-3}) = 40 \text{ db}.$$

Next assume that cracks through the walls at various

[5] The noise insulation factor gives the difference in db between the noise level immediately outside the room and the level of the transmitted noise that is established in the room. Thus if the outside noise level is 70 db and the NIF is 40 db, the level inside the chamber is 30 db.

places amount to 1 sq. in., or 0.007 sq. ft. Since the TL of the cracks is zero db, τ_0 is unity, and the total transmittance T will be $0.007 + 0.001 = 0.008$, and the noise insulation factor of the room will be

$$NIF = 10 \log (10/0.008)$$
$$= 31 \text{ db.}$$

In other words, the cracks reduce the noise insulation factor by 9 db. According to Fig. 4 the transmission loss of a concrete wall increases directly with the weight per square foot of wall section, and each successive doubling of the weight of the partition adds 4.5 db to the transmission loss. Therefore the "leaky" room in the example above is equivalent to one with walls only 1.5 in. thick but without cracks.

The above is truly idealized, because small openings act somewhat in the nature of frequency selective filters.[6] Still, such figures may be borne out in practice. And here, as elsewhere in sound-reducing construction, it should be remembered that the cost of initial preventatives is often but a small fraction of the cost of subsequent corrective measures.[7]

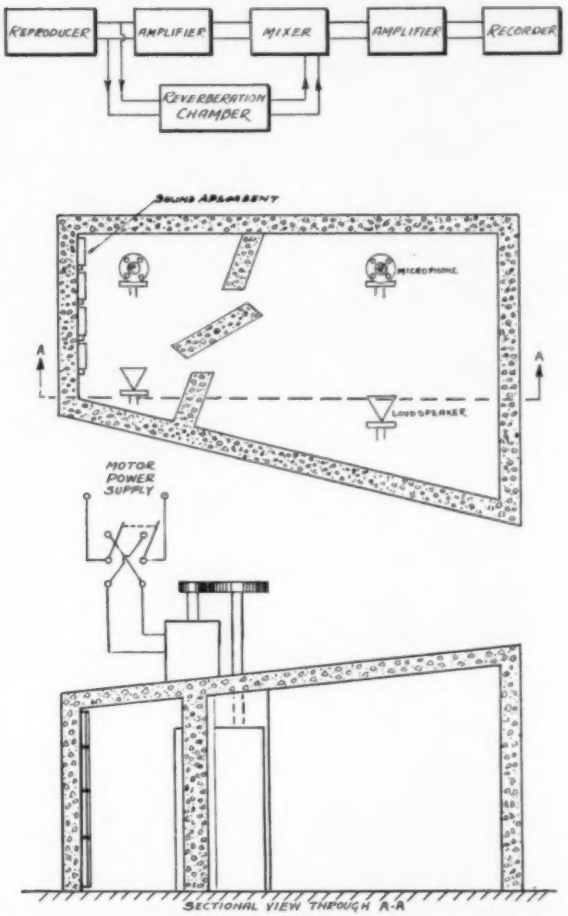

FIG. 3. Diagram of dual reverberation chamber with variable aperture.

TYPICAL ABSORPTION COEFFICIENTS

Figure 4 shows the sound transmission loss characteristic of homogeneous solid walls as a function of the weight per square foot of the walls. Thus, an 8″ thick concrete wall weighing 100 lb./sq. ft. will have a sound transmission loss at 500 cycles of 52 db; at 125 cycles of 40 db; and at 2000 cycles of 64 db.

Table I gives the absorption coefficients of various types of building materials which may be used for finishing the interior of reverberation chambers.[8]

TABLE I. Absorption Coefficients of Various Materials Suitable for the Walls of Reverberation Chambers.

Material	Frequency (cps)					
	125	250	500	1000	2000	4000
Brick wall, unpainted	.02	.02	.04	.05	.05	.05
Brick wall, painted	.01	.01	.02	.02	.02	.02
Gypsum plaster on metal lath, on wood studs	.04	.04	.04	.06	.06	.03
Poured concrete, unpainted	.01	.01	.02	.02	.02	.03
Poured concrete, painted	.01	.01	.01	.02	.02	.02

MINIMUM SIZE REVERBERATION CHAMBER

The question is often asked how small a reverberation chamber may be built to provide satisfactory results. This writer asked a number of users of reverberation chambers of widely varying volumes about the quality of the reverberated sound obtained in the chambers. Invariably, when the room had a volume of less than 1000 cubic ft., the comments were "too boomy," "sound blurry and without much reverberant quality." As a tentative criterion we may say that the minimum length (of the 1 : 1.26 : 1.58 parallelepiped) should be such that the lowest normal mode of vibration corresponds to the lowest frequency to be reproduced in the enclosure. This minimum length, L, is given by

$$L = c/2f$$

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[6] For certain idealized cases, e.g., a narrow slit, (Cf. Olson, *Acoustical Engineering*, 3rd ed., p. 89), an explicit expression for the acoustic impedance can be obtained. From this, by making a wise choice in the parameters of the coupled enclosures and allowing for diffraction at the edges of the crack, the effect of such filters may be calculated. [Ed.]

[7] Further details on the effects of cracks may be found in G. L. Bonvallet, *Noise Control*, 3, 61, (March 1957). [Ed.]

[8] Coefficients for other materials may be found in "Sound Absorption Coefficients of Architectural Materials," *Acoustical Materials Association Bulletin*, 14, 1953. [Ed.]

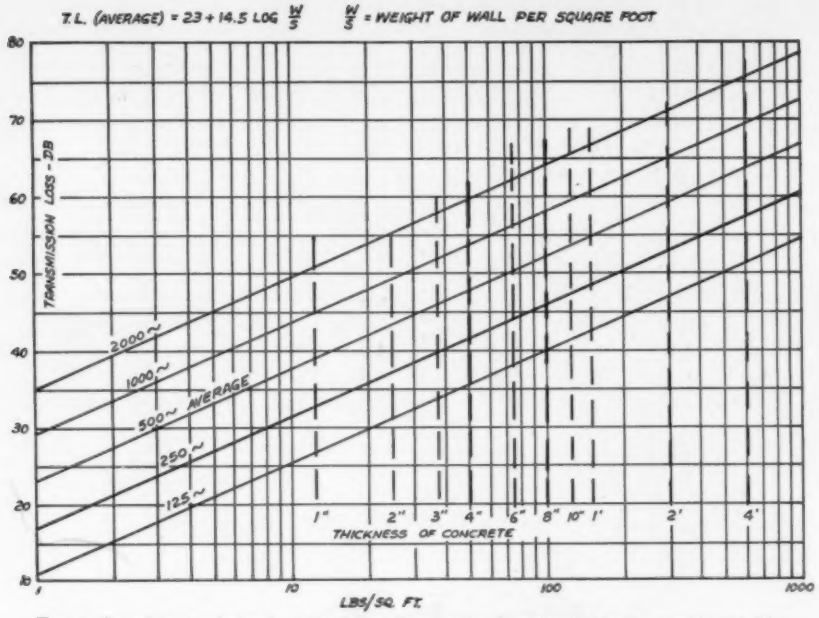

FIG. 4. Sound transmission loss at various frequencies for chambers whose walls are all constructed of a material of given surface density, expressed in lb/sq ft. Abscissas for concrete walls of various thicknesses are also shown.

where c is the velocity of sound, 1130 ft./sec., and f is the lowest frequency to be reproduced. Thus if it is intended to reproduce down to 40 cycles, the minimum chamber length should be 14.1 feet; this gives a room volume of 1400 cu. ft.

SUITABLE SIGNAL LEVELS

The signal level in the reverberation chamber should be no higher than is required to achieve the desired signal-to-noise ratio. Thus, if the noise-level in the enclosure is 40 db (above threshold), and a 50 db signal-to-noise ratio is desired, a signal level of 90 db is called for. High signal levels are definitely to be avoided. Such levels are able to set all kinds of structural elements into resonant vibration, with the result that the reproduced sound becomes adulterated by selective emphasis of signal components. This effect is another factor pointing toward the requirement of locating the chamber in relatively quiet surroundings, such as in basements and on building roofs, and even within the ground.

SUMMARY

We may, therefore, summarize the chief factors to be considered in the construction of reverberation chambers:

1) A desirable ratio of height-to-width-to-length of room.
2) Heavy reflective walls which minimize transmission loss.
3) Prevention of sound leakage into the chamber, to avoid a high noise-level.
4) Location of the chamber in relatively quiet surroundings, for the reason given in (3).
5) Use of a single, non-directional microphone, which remains stationary in the room.
6) Use of one or two loudspeakers which, like the microphone, remain stationary to avoid the frequency modulation resulting from swinging transducers. (Two loudspeakers hold more promise for achieving a more uniform sound output from the microphone on prolonged passages than two microphones).
7) Non-parallel walls or the introduction in the chamber of hard obstacles such as pillars to diffuse the sound in the room.
8) A signal level in the room no higher than is required to achieve the desired signal-to-noise ratio.

The Corona Wind Loudspeaker*

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The discovery in England of a method of controlling the wind produced by a corona discharge provides the basis for a new loudspeaker design having no moving parts and offering other potential advantages over conventional speakers. The inventor of the Corona Wind Loudspeaker is Dr. David M. Tombs.‡

The author first describes the construction of a corona triode in which a ring mounted coaxially about one electrode and given suitable potentials is found to control the discharge and hence the magnitude of the wind. Characteristic curves indicating triode-like behavior for various electrode spacings are presented.

By applying an af voltage to the ring, a sound source results. An early experimental model of such a loudspeaker is described and illustrated, together with its observed frequency response. Comparisons with the Ionophone and the electrostatic loudspeaker are made, which indicate its potential superiority in wide range reproduction. The author discusses the acoustical and electrical problems that arise in the construction of a practical loudspeaker, and concludes with details of the research and development program necessary for its commercial realization.

BACKGROUND

UNTIL RECENTLY corona has been regarded almost universally as an undesirable phenomenon, and such studies of it as have been made were usually undertaken with a view to suppressing it. Most engineers in the communications field are aware that it is a source of hf noise and interference, and that countermeasures are regularly applied to aircraft and high voltage power lines. In the latter case the need to control power losses is a primary concern.

Since so little is known about corona on the positive side, it was necessary to make some rather fundamental tests and observations of the phenomenon, and in particular on the wind that accompanies a corona discharge. A convenient method of observing the properties of these winds—direction, strength and pattern—consists of injecting a smoke stream at low velocity into the corona field.

Starting with the simplest case, a pair of electrodes, one of which was sharply pointed and the other blunt, it was found that only the sharp electrode produces a wind. Further, the wind is stronger when the needle (i.e., the sharp electrode) has a positive potential on it than when it bears a negative sign.

In order to control this wind, it was thought that a smooth ring mounted coaxially around the needle might provide a valve action in the same manner as the grid in a triode vacuum tube. It was found that the corona current could be controlled by changing the potential on the ring, and was also affected by the diameter of the ring as well as by its position with respect to the tip of the needle. In order to measure these several parameters so that the "plate characteristics" of the corona triode could be graphed, special laboratory apparatus with micrometer controls and a series of rings of different diameters was constructed. This apparatus is shown in Fig. 1.§ The triode section is on the left. (The two long needles on the right side were used to measure and plot the resistance characteristics of corona diodes, which could be used as 'loads' for corona triodes. These diode characteristics are shown in Fig. 2.) The E_g–I_p–E_p characteristics of the corona triode for several varying geometries are shown in Figs. 3 and 4. The very interesting similarity of these curves to the plate curves for certain triode vacuum tubes is immediately apparent.

In this form—i.e., with one sharp and one dull electrode plus a ring or grid—the corona triode can act as a "uni-

* Paper presented before the June 12, 1956 meeting of the New York Section of the Audio Engineering Society.

† President.

‡ D. M. Tombs, *Nature*, **176**, 923 (1955).

§ Figures 1 to 5 have been furnished through courtesy of Dr. Tombs.

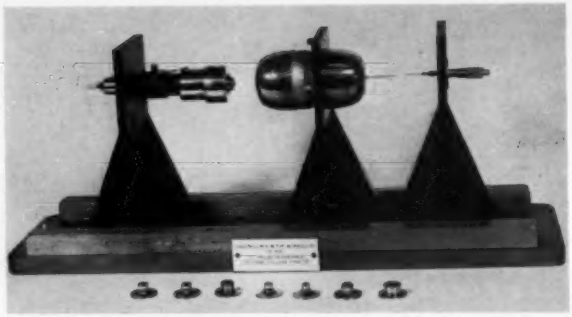


FIG. 1. Laboratory model of the corona triode. The needle and ring-like grid is seen at the left, with the blunt electrode at the center. Grids of various sizes are shown in the foreground.

directional" loudspeaker if an audio signal is applied between grid and the sharp electrode. This is shown diagrammatically in Fig. 5a. The sound output can be described as "modulated dc." In other words, there is a steady (dc, uni-directional) wind accompanying the (ac) sound.

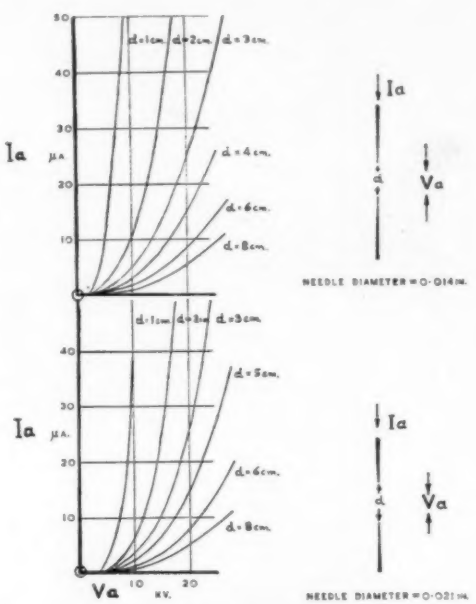
If two sharp electrodes are used in constructing the triode, two opposed winds are created, the positive wind being the stronger of the two, and also having a narrower "beam" as shown by the smoke patterns. By suitable positioning of the grid (and adjustment of its voltage) with respect to the positive needle, it is possible to balance the two winds so that with no signal present there is no "net" wind. This is shown diagrammatically in Fig. 5b.

The amount of sound produced by a single corona triode is very faint, and in order to get sufficient volume a large number of them must be operated in parallel. The first stacked triode speaker which was built utilizes 144 pairs of needles spaced one-half inch apart, giving an outside dimension of $6'' \times 6''$, or one-quarter square foot. This is shown in Fig. 6. The grid was constructed in the form of a screen made up of interlaced wires spaced one-half inch apart. Thus there is a square hole for each pair of needles, and when properly aligned the axes of the needle pairs intersect the centers of the square holes. The supporting structures for the grid and needle matrices shown in the photograph are not the original ones but were hastily improvised by the author, since Dr. Tombs was able to bring only the grid and matrices when he came to the U. S. A. Because of the time element it was not possible to construct a highly accurate structure with guide rails or other similar means to ensure exact mechanical parallelism at all settings, and adjustments have to be made by looking and listening.

The amount of sound produced by this first crude model is still rather small, though it can be reported that AES members sitting in the back row during the demonstration given by the author (June 12, 1956) at a New York Section meeting of the Society in a fairly large room were able to hear what was being reproduced fairly well. It is obvious that a commercially acceptable Corona Wind Loudspeaker (hereafter referred to as CWLS) will have to be considerably larger. Dr. Tombs estimates that four or five square feet may produce adequate volume for home use, though for hi-fi enthusiasts the figure would probably have to be increased. Obviously, too, the ultimate size will be affected not only by the acoustic power output requirements but also by the ultimate efficiency of the device. It is believed that this is one of several factors which can be improved by further research.

CHARACTERISTICS OF THE CORONA WIND LOUDSPEAKER

To any audio engineer, and particularly to any loudspeaker designer, the most significant thing about the CWLS is the absence of any moving parts. Actually this is not the first transducer to convert electrical energy directly into sound. Several years ago the French inventor Klein



ANODE LOAD RESISTANCE CHARACTERISTICS
FOR VARYING GEOMETRY. $I_a = f(V_a)$.
d MEASURED IN CENTIMETERS
K.C.
D.M.T.

FIG. 2. Corona diode characteristics. The corona current I_a depends upon the electrode potential difference V_a, and the separation d. The effect of the needle diameter, 14 mils (above) and 21 mils (below), is not apparent until d is less than 2 cm.

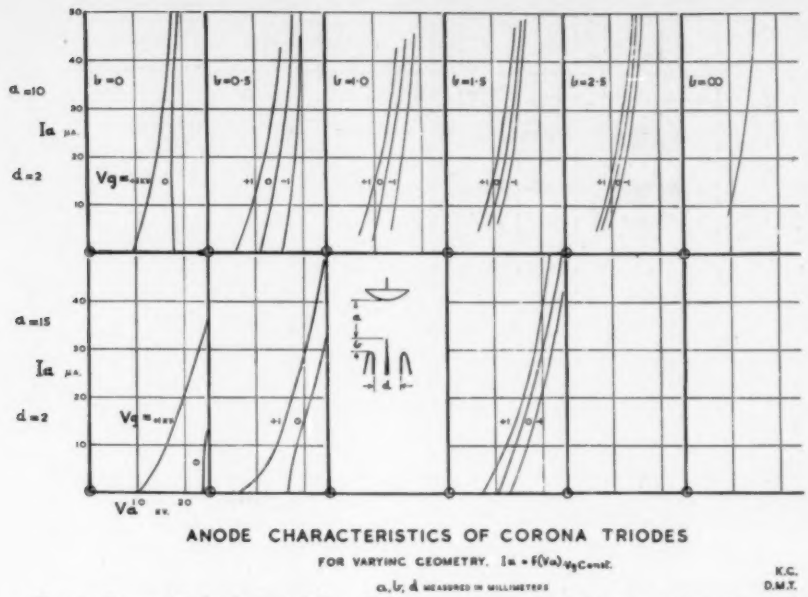


FIG. 3. Corona triode characteristics. The corona current I_a is shown as a function of the electrode potential difference V_a for various electrode spacings and three different grid voltages. At the top, the needle-to-blunt electrode spacing, a, is held at 10 mm, but the needle tip-to-grid distance, b, is varied. Below, a has been increased to 15 mm. In both cases, the needle remains 1 mm away from the grid.

demonstrated his Ionophone[1] which also has no moving parts. On theoretical grounds, at least, the CWLS appears to have certain important advantages over the Ionophone, not the least of which is its wide range, whereas the Ionophone is evidently limited to tweeter applications. Other comparisons which can be made are:

1) the Ionophone is a point source of sound (and a very small point at that) whereas the CWLS is an extended source;
2) the Ionophone functions as a power diode, whereas the CWLS is apparently a triode device, which is more efficient than a diode.

In comparing the CWLS to electrostatic speakers the following points can be made:

1) both are extended rather than point sources of sound, and both are adaptable to push-pull operation;
2) the CWLS can reproduce a wider frequency range, and should be able to create a greater amplitude of air motion at any frequency, both of these advantages deriving from the absence of any diaphragm. (The excursion of the diaphragm in an electrostatic speaker is severely limited);
3) for electrostatic speakers actual watts of audio power are required (to drive an essentially capacitive load) as well as polarizing voltages (these voltages, however, are not high enough to cause ionization).

The requirements for the CWLS, to be discussed in detail further on in this paper, will be seen to be quite different.

Having made these brief comparisons, the discussion will now revert to the characteristics of the CWLS itself, the first of which is its frequency response. The CWLS appears to be capable of covering the entire audio spectrum from zero on up. The very fact that it can produce a wind is prima facie evidence of its low frequency capabilities. However, actual measurements in the range from zero to 20 cycles will present some interesting problems. First of all, to provide an ultra-low frequency signal it is necessary to use a beat-frequency oscillator, since conventional audio oscillators normally extend down to only 20 cycles. Secondly, a microphone which responds all the way down to zero, and is accurately calibrated, is not easily come by—if indeed it exists at all. Subjective judgments are not likely to be of much help considering that the crossover point between hearing and feeling is in the vicinity of 20 cycles. Perhaps a more promising approach would be the observation of the movement of a flame (as from a candle) held in front of the CWLS. This method has been used

[1] S. Klein, *Comptes Rendues*, **222**, 1282 (1946), **233**, 143 (1951), *L'Onde Electrique*, **32**, 314 (1952).

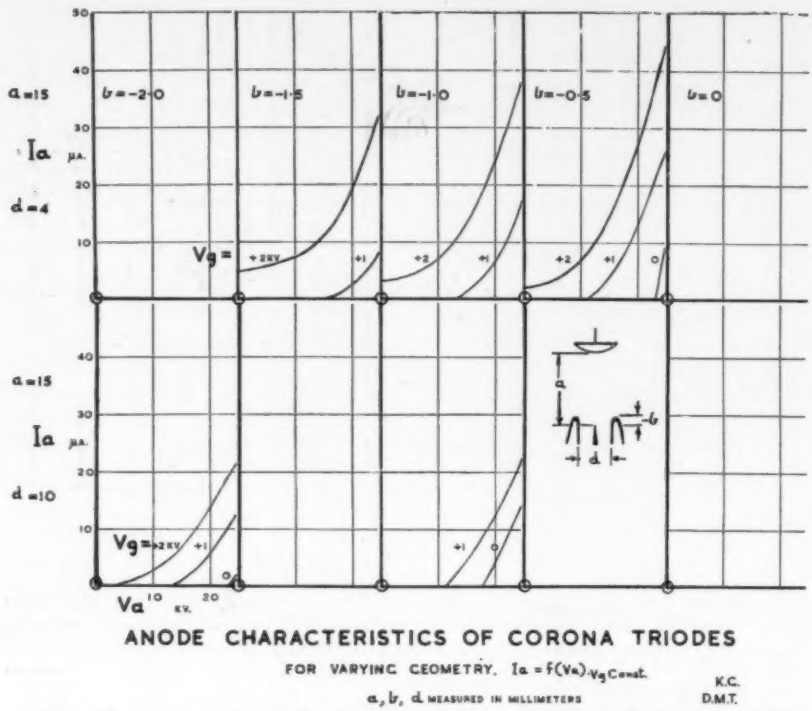


FIG. 4. Corona triode characteristics (cont'd). In this series, the needle is located at varying distances within the grid. The anode-to-cathode distance, a, is maintained at 15 mm in both cases, but the relative position of the needle within the grid is varied, as shown. A 4 mm ring is used in the series at the top, and a 10 mm ring below.

by Dr. Tombs to demonstrate the response at around four or five cycles. It seems likely that a fair degree of accuracy could be achieved in measuring the amplitude of a flame movement by using a specially constructed sighting—or optical projection—device.

The upper limit of frequency response of the CWLS would appear on theoretical grounds to be well up in the ultrasonic region, depending in large measure on the recombination time of an ionized gas. It therefore seems reasonable to anticipate that response to a minimum of 20 kc will be readily obtained.

Due to the absence of moving mechanical parts (and associated suspensions) the overall response curve is in general much smoother than that obtained from a typical cone-type speaker. In Fig. 7 there is shown a curve taken on the first model. The measurements were made with a calibrated microphone over the range shown. This is obviously not yet a "flat" response, and indeed it would have been surprising if perfection had been obtained on the first try. Even so, this curve represents a deviation from flat response of only 3.5 db, assuming a reference frequency of 1500 cycles. The dip at 8000 cycles, which is the only pronounced irregularity in the curve, is apparently related to the physical spacing between the tips of the two sets of needles and corresponds to a half-wavelength at the indicated frequency. Since the spacing can be varied, the position of the dip can be moved up or down, though it is unlikely that this would be the decisive factor in establishing an optimum spacing. More important, it is believed that there are several approaches which could succeed in minimizing the amplitude of the dip, if not in eliminating it completely.

The CWLS is not immune from the degradation of low frequency performance which results from cancellation effects between front and back radiation. In other words baffling is necessary. Depending on the application and the desired low-end response, either a bass reflex or an infinite baffle type enclosure could be used.

No measurements have been made on the polar dispersion pattern as a function of frequency. Theoretically the CWLS should show an increasing tendency towards beaming as the frequency is increased, and subjective judgments based on listening to an audio oscillator indicate that this is so. (In this respect the CWLS is similar to electrostatic

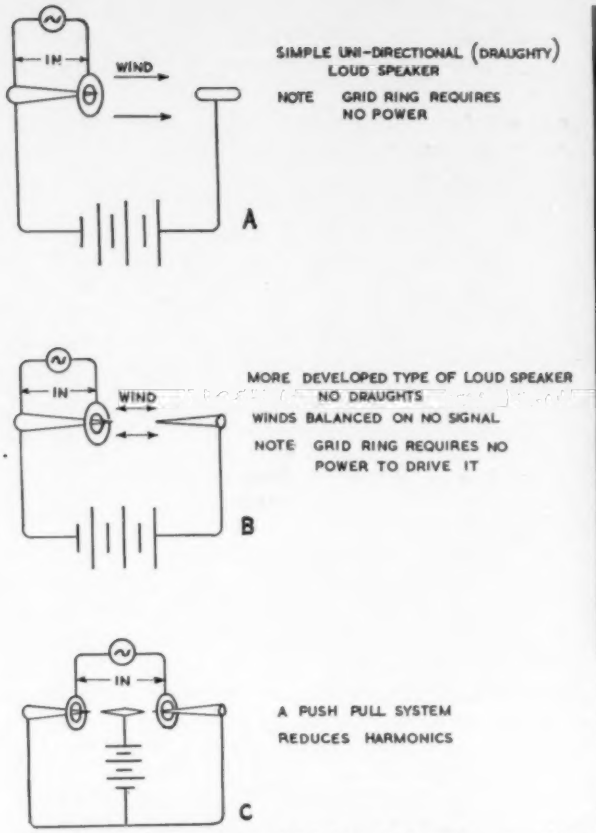


FIG. 5. Schematic diagram of triode as loudspeaker. A. With the polarities shown, an audio signal applied to the grid produces a wind in the anode direction. B. Replacing the blunt anode with a needle causes winds in both directions. C. Push-pull arrangement.

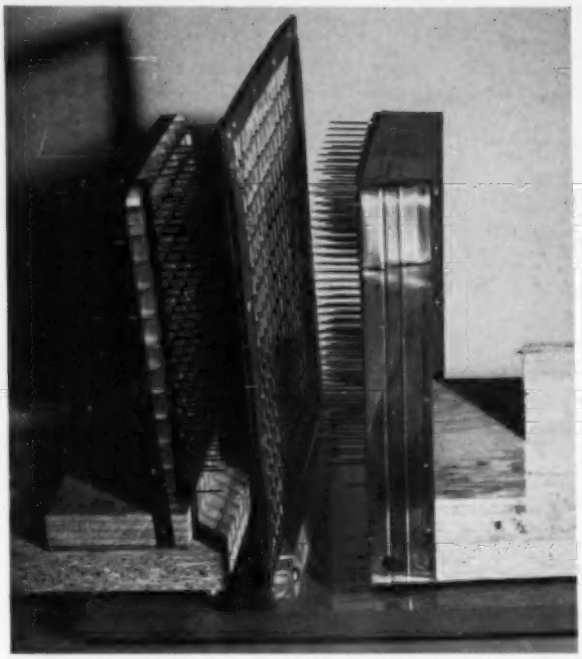


FIG. 6. Experimental form of loudspeaker as an extended source. The grid is a screen with square holes, one-half inch wide. The axes of each electrode pair pass through the center of the corresponding hole.

speakers.) In production models uniform sound dispersion through any desired angle could be obtained by constructing the needle matrices and grids in a curved section rather than in a flat plane. Since these members have to be made rigid anyway, it is thought that there should be no great difficulties in constructing the speaker with a curved cross-section. Alternatively it could be made in narrow planar segments joined together so as to approximate a curved section of any desired arc. Inasmuch as satisfactory vertical dispersion patterns are (evidently) obtained in electrostatic speakers without curving them in two planes, the chances are that double curvature would not be necessary in the CWLS either.

Measurements on distortion have not yet been undertaken. These will be part of the program of research and development on the CWLS, one of whose aims, of course, will be to chart all the relationships between distortion and the various electrical and mechanical parameters. With the first model which is in the author's possession, some distortion is definitely audible, and seems to vary with the mechanical "settings" of the matrices and grid (which are

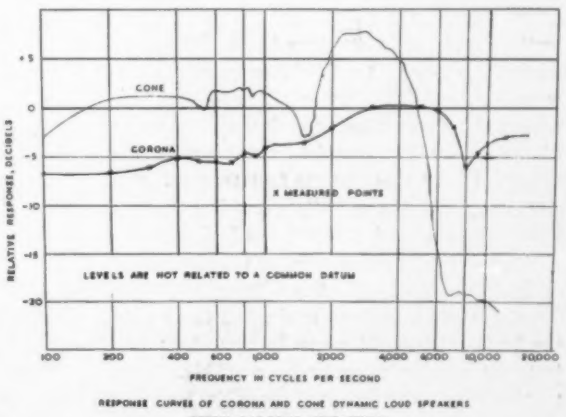


FIG. 7. Frequency response of the experimental loudspeaker. The dip at 8 kc results when the electrode separation is $\lambda/2$ of the applied signal (see text).

not highly accurate, as previously explained), and also on the amount of drive voltage fed into it. The CWLS can be overdriven like any other transducer (despite the absence of a diaphragm), and in playing around with the small model there is always the desire to crank up the volume in order to hear it better. It is interesting to speculate on whether the CWLS may not be inherently less susceptible to intermodulation distortion by virtue of its weightless "invisible diaphragm."

Still on the subject of distortion, a very important point to consider is that the configuration which has been discussed thus far is single-ended—both the speaker and the driver amplifier. It is very easy to construct the CWLS in a symmetrical, push-pull form, one version of which is shown schematically in Fig. 5c. Dr. Tombs has since constructed a push-pull model and reports that the performance is definitely superior to that of the first (single-ended) model. It is driven by a push-pull amplifier with negative feedback over the output (driver) stage only. The possibility of applying *over-all* feedback—with all of its well-known benefits—is one that will naturally occur to most readers, and there are several methods whereby this could be accomplished.

Measurements on the acoustic output of the first model show that for minimum audible distortion a figure of about 0.1 mw/sq. cm. is attained, and it is believed that this is roughly comparable to the output of electrostatic speakers. The electrical power input (dc) is about 50 mw/sq. cm. at 12 kv. A quick calculation shows that the efficiency is quite low, but as mentioned earlier, this factor may be susceptible of improvement. Whether such improvement would be nominal or considerable only time and further research will tell. Direct comparisons of efficiency with cone-type speakers are not completely relevant, since with these the lowest level of efficiency which can be tolerated is in part dictated by the economics of providing sufficient watts of audio power to drive them. This is not a desideratum in the case of the CWLS, since only an audio *voltage* is required to drive it, regardless of its physical size and acoustic output. There remains, of course, the economics of the high voltage supply for the corona field, and from this standpoint it is obvious that the goal of improved efficiency will have a priority second only to the goals of linear response and elimination of all distortion.

It is frequently asked whether the background hiss of the corona discharge is objectionably audible. No quantitative measurements have been made, but those who have heard the first model would generally agree that with proper adjustment the hiss is practically inaudible. Starr[2] has shown that radio interference and acoustic hiss can be greatly reduced by using a slender needle. Though the needles used to construct the first model are of small diameter, it is by no means certain that they represent an optimum selection from the viewpoint of hiss-suppression. At close settings of the needle matrices it is necessary that all the tips of each set of needles lie exactly in a plane, and that the two planes be exactly parallel to each other. If this condition is not met, then as the matrices are brought closer together whichever pair of needles has the smallest inter-tip spacing will pass a higher than average corona current and this will be accompanied by audible hissing. As the matrices are moved still closer, at some point arc-over will occur as the dielectric strength of the air is exceeded. In a darkened room one can see the corona discharge, which takes the form of a tiny blue glow at the tip of each needle.

[2] E. C. Starr, A.I.E.E. Technical Paper 40-118 (May 1940).

DRIVE REQUIREMENTS FOR THE CWLS

The required amplitude of the audio driving voltage is in the neighborhood of one to two kv peak to peak. At first glance this may seem like a serious and costly obstacle, but in reality it is quite simple to achieve, inasmuch as a high voltage supply (at least 8 kv) is already required for the corona field. The only other elements needed are a suitable voltage amplifier tube and a load resistor. There are currently available special purpose tubes such as the 6BK4 and 6BD4A originally designed for regulator use in high voltage power supplies, which perform very satisfactorily in this application. These tubes draw very little current and have an amplification factor of 2000. Thus it is necessary to apply only a few volts to the grid in order to get the required 1 to 2 kv swing at the plate which is directly coupled to the grid of the CWLS. The circuit employed in the experimental model is given in Fig. 8.

POWER REQUIREMENTS

The power requirements for the corona field vary proportionately with the number of needle pairs and in inverse ratio to the distance between the opposed tips. The effect of increasing or decreasing the spacing between (adjacent) needles is not yet known. The amount of current drawn is also influenced by the mechanical configuration of the grid structure, its position relative to the needles, and the voltage on it. According to Dr. Tombs' measurements on the first model, each needle pair passes "some tens of microamperes" of current. No precise figure can be given, of course, without defining all the electrical and mechanical conditions.

The minimum voltage required is one that will cause a corona discharge, and maintain it with an adequate margin of reserve to overcome any conditions which might tend to "quench" it. The maximum—tolerable—voltage will be defined by considerations of efficiency, performance, cost, hiss, safety, and so on. There is evidently a wide range

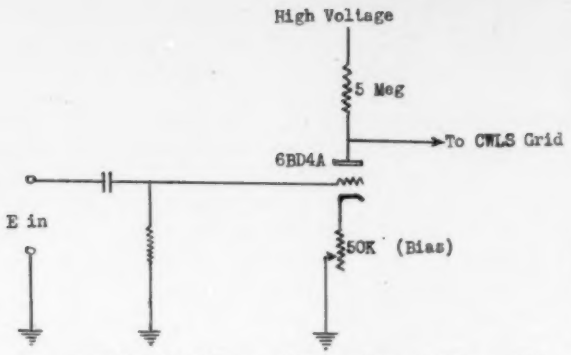


FIG. 8. Schematic diagram of high voltage af driver. With a voltage gain of about 60 db, and an anode supply voltage of from 10 to 20 kv, an audio signal of 1 to 2 kv appears at the anode.

of usable voltages, and one of the goals of the R and D program will be to determine the optimum value.

NON-ACOUSTIC OUTPUTS OF CORONA TRIODES

As an electronic amplifier, the corona triode has a voltage gain of about 3. No especially useful application comes to mind for this, and any suggestions would be welcome. Someone has pointed out that a corona triode—or several in cascade—could be used to obtain the high driving voltage required for a CWLS. This is an intriguing idea, but is probably doing it "the hard way".

The other non-acoustic output of corona triodes is ozone and nitrous oxide, which are by-products of the corona discharge. This will have to be studied carefully to determine whether it presents a health hazard.

RESEARCH AND DEVELOPMENT PROGRAM FOR THE CORONA WIND LOUDSPEAKER

A program of research and development aimed at bringing the CWLS to a point where it can be commercially produced could logically start with a careful investigation of the corona wind phenomenon itself. There are certain fundamental questions whose answers might well save time during later phases of the program. For example: What actually causes the winds? Is the relationship between wind velocity or volume and corona current linear? A search of the literature might uncover earlier studies which could reveal useful information, but it is thought likely that the bulk of references will concern various (usually harmful) effects of corona and methods of suppressing it. In the present instance the goal is to encourage corona—not to discourage it.

The first phase of the R and D program will undoubtedly consider the CWLS only as a wind producing mechanism (corona diode), and will be concerned with investigating and measuring the effects of the various mechanical and electrical parameters on efficiency and hiss. Efficiency would be defined, of course, as the ratio of wind out to power in.

On the mechanical side the starting point of the investigation would be the electrodes themselves. The effects of varying the length, diameter, including angle, and tip radius will all have to be individually determined. It would probably be unwise to start out with any preconceived notions as to what the effects are going to be. In fact, it should not even be assumed that a needle shape is necessarily the best for electrode use. Other shapes and configurations should also be tested. For example, one could try thin-wall tubing of various diameters, down to hypodermic needle sizes, and with various treatments of the emitting ends, such as bevelling (to get a fine edge) or flaring.

On the electrical side, it will be necessary to determine the relationship between power in and wind out, and also whether it makes any difference if the power consists of high voltage at low current or vice versa. Of course, the voltage always has to be high enough to start and maintain the corona discharge, but from that point on there is quite a range.

Dr. Tombs has made an interesting suggestion concerning the possibility of making the tips of the needles radioactive. Ionization should thereby be aided, but whether this would increase the efficiency could only be determined by actual tests.

Not only are the velocity and volume of wind important but also its direction. Dr. Tombs' smoke experiments have shown that positive winds are more tightly 'beamed' (forward) than negative winds. The latter have an umbrella shape. Presumably a negative wind would yield less acoustic output, when modulated, than a positive one. It is possible that by suitably manipulating the dimensions and geometry of a negative electrode its wind could be made more nearly coaxial. (But it is not a foregone conclusion that this would be desirable.) Another interesting possibility is that of somehow turning the negative wind around so that it aids instead of opposes the positive wind.

During the corona diode stage of the R and D program it might be well to get started on a study of the effects of varying humidity levels. Offhand it would seem that a high humidity level might aid the flow of corona current, thus setting a limit to how close the opposed electrode tips could be. In other words, mechanical and electrical specifications might have to be chosen so that arc-over would not occur during periods of abnormally high humidity. If this limitation were found to exact too great a penalty on efficiency (during periods of normal or low humidity), then it might be worthwhile to incorporate a compensating circuit using a humidity-sensing transducer which would automatically adjust the voltage level in reference to the humidity level.

When all the facts are in on the corona diode as a wind producer, the next phase will concern itself with corona triodes. The first subject for consideration is the grid structure. The size and shape of the openings, the width of the walls, the thickness of the structure—all these will have to be individually varied to determine their effects (if any) on efficiency, frequency response and distortion. Tests should also be made with finer mesh grids to see if they offer any advantages over structures which have one hole for each pair of electrodes.

The positioning of the grid with respect to the electrodes is already known to have a significant effect on the operating characteristics, and accurate measurements to chart these relationships will be an important step. Not only does the position of the grid have an effect but also the electrical operating point—i.e., the no-signal dc voltage. If an analogy to vacuum tube operation is valid (and it certainly seems possible on the basis of the triode characteristics), then it may be possible to obtain various types of operation—i.e., Class A, Class AB^1, Class AB^2, and so on. This could be of significance in later work on the push-pull versions.

Another mechanical variable is the spacing between adjacent electrodes, and this brings up an interesting point. Though the CWLS does not have any moving parts there is a strong temptation to postulate an invisible diaphragm; this leads to some questions as to the physical properties of this diaphragm. Specifically, how porous is it? And does the porosity vary with frequency? The relationship between porosity and efficiency must be fairly obvious. It may turn out that an electrode spacing which yields maximum efficiency at low frequencies (long wavelengths) results in an intolerable attenuation of high frequencies. If such a condition is in fact found to exist, then several solutions are available, the most obvious one being a compromise spacing. Still on the subject of porosity, it may be pertinent to ask whether a negative wind may not be less porous than a positive wind. The reason for this could be that the winds from each electrode in a negative field blow not only forward but also sideways towards the other electrodes. This could perhaps have the effect of making the invisible diaphragm more impervious—i.e., less porous, hence more efficient.

When the analysis of the CWLS as a single-ended transducer is complete, and the effects of every single variable on the operating characteristics (and on each other) are thoroughly understood and measured, then the next phase —push-pull operation—can be started.

However, before too large an expenditure of time and money is made on the development of the CWLS as an air-operated device, it might be well to determine whether its production of ozone actually constitutes a health problem, and if so whether it can be overcome. If it cannot, then the CWLS will be developed for operation in an inert gas, such as argon. In this case the speaker would be mounted in an infinite baffle type of enclosure, but instead of the usual solid front panel (for mounting the speaker) there would be a thin plastic membrane, such as Mylar. (Actually both the speaker and membrane could be set in a short distance from the front edge of the cabinet so that a grill cloth could be attached in front.) In order that the usual drawbacks of diaphragms and elastic suspensions may be avoided, the membrane would probably not be fastened under tension, but would rather be loose and floppy, serving chiefly as a separator between the gas inside and the air outside. While at first glance gas operation might seem to be an undesirable complication, nevertheless it may offer some unsuspected advantages such as better efficiency, lower distortion, etc. One known advantage is that there would be no problem of metal corrosion, which does exist with air operation. The ozone and nitrous oxide which result from corona discharges in air have a corrosive effect on certain metals. Dr. Tombs has suggested that it may be possible to neutralize these chemical compounds by providing a "sacrifice" material within the speaker enclosure which the compounds could attack. (The analogy to sacrificial magnesium anodes used in water tanks and on ship hulls comes to mind.) The electrodes, or their emitting tips, could be made of stainless steel or some other corrosion-resistant metal. The grids and support structures could be made of less expensive metal and protected by a coat of suitable plastic (such as du Pont Hypalon).

In experimenting with push-pull configurations different combinations of electrodes—positive, negative, sharp, blunt —can be tried, as well as various classes of operation (Class A, Class AB^1, etc.). As mentioned earlier, it may be worthwhile to try to turn the negative winds around so that they aid their respective positive winds. In this way each half of the speaker would produce one wind instead of a pair, and this might improve certain of the operating characteristics.

With push-pull operation, excitation of the corona field by rf power (instead of dc) may be feasible, and this presents a number of interesting possibilities which should be looked into. (The analogy to high frequency bias in tape recording comes to mind, though it may not be a valid analogy.)

Still on the subject of power supplies, the subject of regulation is one that would probably be started on during the earlier single-ended phase of the program and would of course continue on through into the push-pull phase. Since the cost of power supplies bears a direct relation to the degree of built-in regulation, it is clear that one of the goals of the program will be to find a combination of mechanical and electrical parameters which will yield optimum acoustic performance and at the same time require as little

regulation as possible in the power supply.

The last important project will be the development of an over-all feedback system so that any residual distortion or irregularity in the response curve will be eliminated, or at least reduced to insignificant proportions. This boils down to finding a suitable transducer to sample the acoustic output and provide a corresponding voltage which can be fed back into the driver amplifier. A microphone comes to mind immediately, of course, but it must be remembered that ordinary microphones are neither wide-ranged (compared to the CWLS) nor particularly flat. It might be possible to make a very simple condenser type of microphone at low cost which would be incorporated right in the speaker.

In summary, one can fairly say that the complete R and D program for the CWLS will represent a rather extensive undertaking. However, there appear to be good reasons for believing that the final results should fully justify the costs of the program.

Note Added in Proof

After completing this paper, the author sent a copy to Dr. Tombs for his comments. In his reply, Dr. Tombs calls attention to an error in the description of the corona wind:

> "It is obvious that I have not made myself clear about the shape of the negative corona wind. This is not umbrella-shaped in the absence of a positive wind. Positive and negative winds separately are similar in shape, the positive being rather stronger than the negative, and it is the interaction of these two blowing simultaneously which appears to give the umbrella shape in the proximity of the negative electrode."

He also comments on the drive requirements and the efficiency comparisons:

> " . . . I suggest . . . that you should mention that only very small power is required to drive the Corona Loudspeaker, the power being primarily to make good the losses in . . . the way . . . the driving power of the grid of a valve . . . has to make good the losses . . . It might be worthwhile pointing out that the efficiency of ordinary loudspeakers is very low and the power required to drive them is not a measure of the acoustic power generated. The CWLS requires negligible power. The loudspeaker is in fact a control device like a valve, in which the power is supplied by the polarizing high voltage source."

EDITOR'S NOTE: Additional photographs and description of the CWLS may be found in the recent paper: D. M. Tombs, E. J. Chatterton, and K. Galpin, *Electronics*, 30, No. 7, p. 198 (July 1, 1957).

Gallina

(*Continued from page 10*)

"16mm Projector" lever switch to "Meter" position. By flipping to "Monitor Speaker" position, he can listen to the quality of the sound as it is heard by the audience. The "P.A. System" switch likewise performs the same function for the public address system amplifier.

The "Adjust Monitor Speaker" and "Adjust Meter" controls are used to adjust the setting of the meter and the volume of sound heard over the monitor loudspeaker without affecting the sound directed to the listening audience. The sound level meter and the monitor loudspeaker can be disconnected by setting both lever switches at their center position.

Equipment

1. Ampro optical and magnetic model #477 motion picture projector, equipped with a dynamic microphone and head phone and mixer.
2. Viewlex 500-watt filmstrip (single and double frame) and 2 × 2 slide projector model V25C.
3. Bogen amplifier with 3-speed turntable model J330—2 microphone low impedance channels, 1 high impedance phonograph channel, 1 high impedance tape recorder input.
4. (2) University type BLC weatherproof wide range loudspeakers.
5. Pentron 2-speed tape recorder model T90.
6. (2) clusters of weatherproof floodlight sockets, each supplied with 25 feet of power cord, having a 2-pole, twist-lock male plug.
7. (4) Atlas model SS-2 collapsible weatherproof heavy duty stands: (2) for the University BLC loudspeakers, (2) for floodlights, adjustable from 5 to 10 feet.
8. (2) Shure 55S "Unidyn" multi-impedance microphones equipped with 50 feet of shielded 2-conductor cable fitted with matched 3-pole XL-3-11 microphone connectors.
9. (2) Atlas type MS-11c adjustable microphone floor stands.
10. (2) Heavy duty American Television and Radio dc to 115-volt 60 cycle ac inverters: (1) Model 12T-HSH 12-volt dc to 115-volt 60 cycle at 200 watts. (1) Model 110T-HSH 110-volt dc to 115-volt 60 cycle at 400 watts, with extra replacement vibrators.
11. (6) General Electric 150-watt 115-volt floodlights (reflector type).
12. (1) 75-foot extension cord for the 16mm motion picture projector speaker, equipped with a 2-pole phone plug.
13. Fold Fast 7½ × 10 ft. collapsible mildew-proof screen with aluminum frame.

CONCLUSION

In summary, we can say that from the technical point of view the task of the overseas audio-visual worker is not an easy one. It offers a major challenge to his patience, to his persistence, and to his mechanical ingenuity.

Tape Storage Problems*

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When magnetic recording tape is stored, its subsequent performance is determined by the physical and magnetic characteristics of the tape material, as well as by its storage environment. Care must be exercised in selecting the proper type and thickness of the base material and in the choice of magnetic coating formulation. Close control over climatic conditions during storage, an even wind without excessive tension, and adequate reel packaging reduce physical damage.

Data which indicate the superiority of Mylar‡ base tapes under stress and varying temperatures and humidities are presented. It is observed that prolonged storage produces no apparent increase in the distortion content of recorded material, whereas the print-through definitely increases with time, and is aggravated by the presence of stray magnetic fields and high temperatures. Procedures which minimize the adverse effects of storage are summarized in conclusion.

A British paper claims that exposure to hydrogen sulfide causes a loss of playback level; we have been unable to find any such effect with Audiotape.

CONTROL OF storage conditions and proper selection of tape for a specific application can greatly reduce the severity of tape storage problems.

Changes in the performance of tape, due to storage, can be classified as physical or magnetic in nature. The physical changes are influenced by the type of base material, climatic conditions, winding stress, smoothness of wind, formulation of the magnetic coating, packaging and time.

PHYSICAL CHARACTERISTICS

Permanent Elongation

Much has been presented on the superior strength and stability of Mylar as compared to cellulose acetate.[1] The choice of base material is so important when storage problems are considered, that additional data are warranted. It is believed that the following elongation tests correlate more closely with effects encountered in practice than do the usual tensile strength and yield studies.

The set of curves in Fig. 1 compares the results obtained when Mylar and acetate base tapes are subjected to increasing tension under "normal" climatic conditions (75° F., 50% relative humidity). A three-foot length of each base material was subjected to increasing stress by the successive addition of weights to a pan attached to the free end. The percent elongation was measured one minute after each weight was added.

A 0.5% elongation is produced by weights of 7 oz. for 0.5 mil Mylar, 14 oz. for 1 mil acetate, 17 oz. for 1 mil Mylar, 22 oz. for 1.5 mil acetate and 32 oz. for 1.5 mil Mylar. Figure 1 demonstrates that the Mylar bases are superior to acetate bases of corresponding thickness in resisting elongation under stress, under "normal" climatic conditions. The 0.5 mil Mylar base elongates at very low tensions and should be used with extreme caution.

Since a "normal" climatic condition is seldom available in tape operations, Fig. 2 shows the result when the relative humidity is raised to 90% at the same temperature as before. The base material and test techniques are identical to those used for Fig. 1.

The elongation curves for the Mylar bases remain unchanged by the increased humidity, whereas the acetate bases have been very adversly affected. The 1 mil acetate base elongates 0.5% at only 5 oz. of stress compared to the 7 oz. required for 0.5 mil Mylar. The 1 mil Mylar, which yields the same elongation for 17 oz., is now superior even to the 1.5 mil acetate, which has dropped to 11 oz. In view of this, it is obvious that winding tension should be carefully adjusted when tape is to be stored for long periods of time, for a tape will become deformed if it has been wound with a tension sufficient to produce 0.5% elongation, and this will result in pitch and timing problems.

* Presented at the Eighth Annual Convention of the Audio Engineering Society, New York, September 26, 1956. Revised paper received April 22, 1957.

† Director of Quality Control.

‡ DuPont trademark for its polyester film.

[1] C. J. LeBel, *Audio Record*, 10, 7 (May 1954).

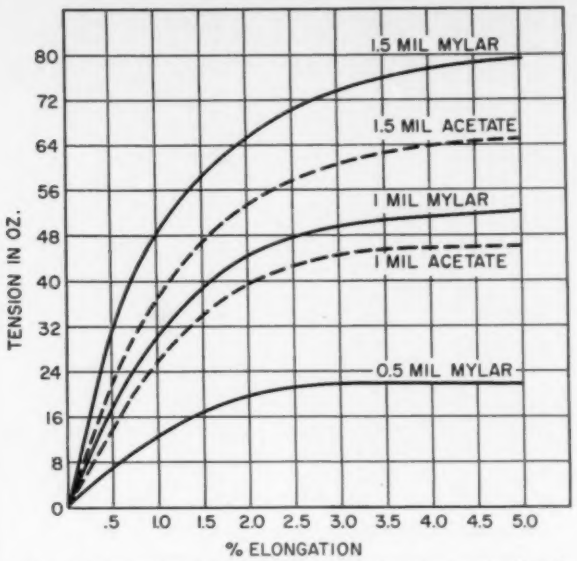

FIG. 1. Elongation produced by stress under "normal" climatic conditions. Temperature of 75°F and 50% relative humidity; 3 ft samples. Test procedure as described in text.

Humidity and Temperature Effects

The susceptibility of acetate base tape to moisture must be seriously considered during storage. Changes in the relative humidity, such as those experienced during the summer months, can completely destroy the usefulness of acetate tape in storage. Expansion and contraction of the acetate due to the varying degree of moisture absorption result in stresses which exceed the yield point of the plastic. Tape with this type of damage is usually recognized as "stretched"; and it appears to "fish-tail" through the guides of a transport. At any given moment, as this "stretched" tape passes over a magnetic head, one edge of the tape is subjected to the normal stress of the equipment, while the other edge may not even contact the head. The excessive stress that one edge sustains causes head deposit which later breaks from the heads and is then interleaved into the tape layers of the take-up reel, becoming a drop-out at the next pass. Flutter, poor tracking and irregular head wear also result.

Extremely high temperatures must be avoided. Acetate tapes should not be subjected to temperatures greater than 100° F., to avoid the extreme physical distortion which results from the loss of moisture. Mylar tapes can withstand 200° F. for extended periods when wound on a reel, without noticeable physical deterioration. However, the standard plastic reel begins to soften at about 175° F. This can cause the loss of a valuable recording. Therefore, for storage where temperatures are likely to exceed 150° F., the use of Mylar base tape and a metal or high-melting plastic reel is recommended.

Mechanical Considerations

Smoothness of Wind. The smoothness of wind is important for both Mylar and acetate tapes. When a reel is so wound that layers extend above the plane of the edges of the adjacent layers, these unsupported layers are subject to abuse from the tape reel flanges and from handling in general. Unsupported layers of acetate tape will very quickly become "rippled" and consequently permanently distorted. Layers of unsupported Mylar will also become distorted with time due to the rapid release of the plastic stress applied during the winding operation. The smooth layers adjacent to the unsupported ones must slowly dissipate this stress through a cold flow process, because their compact relation allows very little physical movement.

Packaging. The type of package within which magnetic tapes are stored for long periods must be considered. For acetate tape, a moisture-proof container is essential, unless properly stabilized climatic conditions can be maintained. In any event, some sort of container is necessary for all tapes, to prevent dirt accumulation which would pile up on the heads to cause drop-outs. The package should be sturdy enough to withstand reasonable handling and stacking.

Rewinding. The longer tape is stored, the more perma-

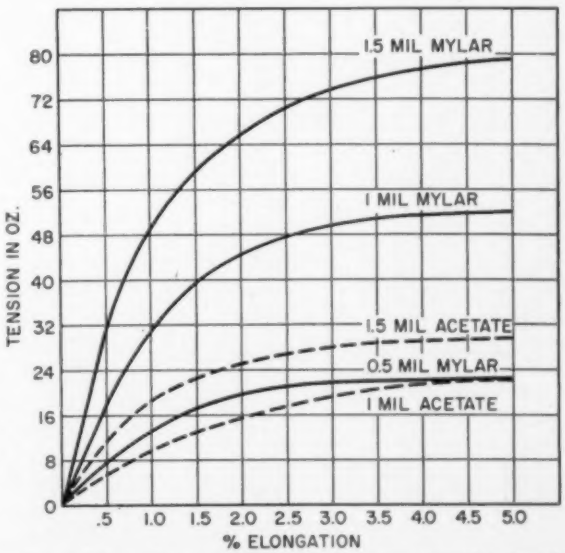

FIG. 2. Elongation produced by stress under "humid" climatic conditions. Temperatures of 75°F and 90% relative humidity; 3 ft samples.

nent the physical distortion due to stress relief becomes. If tapes are to be stored for long periods, and the recorded information warrants the extra time and expense involved, it is advisable to rewind the reels every 6 to 12 months.

Formulation

The formulation of the magnetic coating is of course the manufacturer's never-ending problem. The coating must withstand the physical abuse previously described without interlayer sticking, separation, or wear. Occasionally a particular application may push a tape beyond its limitations. This is rare, however, and can be met by special formulation techniques.

MAGNETIC CHANGES

The changes in magnetic characteristics, due to storage, are influenced by the thickness of the base material, temperature variation, type of packaging, and time.

The magnetic characteristics now to be studied are aside from the physical distortions previously discussed and include intermodulation (IM) distortion, harmonic distortion and print-through.

IM and Harmonic Distortion

A three month study of IM distortion employing low frequencies ranging from 60 to 400 cps in combination with high frequencies of 2 kc, 7 kc and 12 kc, was made, employing ratios of 1 : 1 and 4 : 1. Tape recorded with these frequency and ratio combinations was subjected to temperature variations from 70° F. to 200° F., external magnetic fields, accelerated aging tests and a three month storage period at normal room temperatures. No measurable differences were noted.

It appears that there is no change in IM distortion of a tape recording due to storage under "normal" conditions over a one year period, except that which arises as a result of physical distortion of the tape.

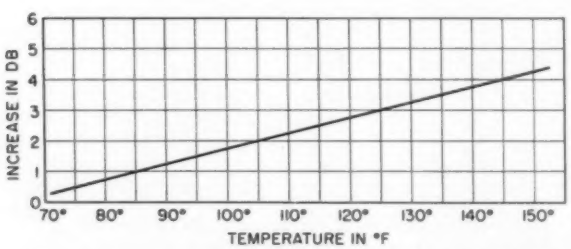

FIG. 3. Increase in print-through as a function of temperature. Tape speed, 7.5 ips; standard reference recorder; 400 cps signal; bias set at peak; and level set to give 3% total distortion. Test procedure is given in text.

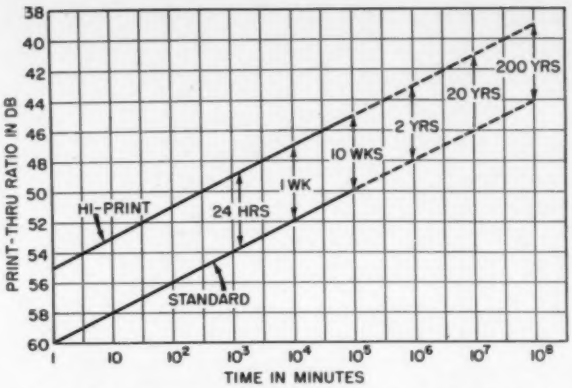

FIG. 4. Print-through as a function of time for a standard and a HI-Output tape. Test conditions as in Fig. 3. (Note: in the figure, Hi-Print should be HI-Output.)

Harmonic distortion at 400 cps and 1000 cps was studied in the same manner as IM distortion, and also remained unchanged throughout the test period.

Print-through

The effect of print-through is the most apparent of the magnetic characteristics influenced by storage conditions and procedures.[2] It is also the most detrimental. Among the factors that influence the extent of print-through are: the thickness of base material, the ambient temperature, the duration of storage, and the presence of extraneous magnetic fields. The effect of each factor was observed in the work to be described in the following paragraphs.

Base Material. The thickness of the base material determines the spacing of the magnetic layers in a reel of tape, and therefore has considerable effect on print-through. Measurements were made using a 0.5 mil coating on bases with various thicknesses from 3 mils down to 0.5 mil, in 0.5 mil steps. The print-through was found to increase approximately 4 db with each change. For applications where valuable music is to be stored for long periods, a thicker base material, therefore, insures a margin of safety.

Temperature. Temperature control of the storage area is necessary to prevent serious print-through as shown by Fig. 3. The test tapes were recorded with a 400 cps signal at 3% total distortion, and peak bias, on every fourth revolution of the take-up reel at 7.5 ips tape speed. Separate reels slit from the same master roll were used for each temperature. The print-through was measured at various temperatures over the range 70° F. to 150° F. after remaining one hour at each test temperature. The print-

[2] C. J. LeBel, *Audio Record*, 11, 7 (June-July 1955).

through increased approximately 2 db for each 40° F. rise in temperature, or 0.5 db for each 10° F. rise.

Time. Figure 4 plots the increase of print-through against time of storage for a standard tape and a specially prepared HI-Output tape. Again a 400 cps signal was recorded every fourth revolution of the take-up reel at 3% total distortion, peak bias, and 7.5 ips tape speed. Measurements were taken periodically over a three month period. By plotting the increase in flux in db on a linear scale, and the time in minutes on a logarithmic scale, a straight line was obtained. This correlated very closely with previous long term tests taken in this laboratory, and with the data obtained by Westmijze.[3] Note that in the first 16.6 hours the print-through has increased 6 db on both tapes. A further increment of 6 db will take about 2 years if the process continues at the same rate (broken lines). Also note that the HI-Output tape appears to remain at its 5 db poorer ratio, compared with the standard tape. Obviously unless the storage period extends over many decades or the print-through is aggravated by high temperatures or stray magnetic fields, most of the print-through occurs within the first few days of storage.

External Magnetic Field. The effect of small, external magnetic fields was also studied (Table I). To obtain the data for this table a special HI-Output tape was recorded with a 400 cps signal as before.

TABLE I. Effect of 60 cps ac Field on Print-through.

Distance above source	Field flux density	Signal-to-print ratio	Signal level loss
control	zero	46 db	0 db
3.25 in	46 lines/cm²	44	0
2.75	65	42	0
2.12	128	38	1
1.50	186	30	3
0.87	303	15	33

For the "control" reading, the tape was heated for 4 hours at 150°F to stabilize the print-through. It was then placed over a 60 cps bulk eraser and slowly lowered. At 3.25 inches above the eraser the flux measured 46 lines/cm² and an increase of 2 db in print-through was noted, with no drop in signal level. The print-through continued to increase as the reel was lowered, and at a field strength of 128 lines/cm² (which occurred at 2.12 inches away), a 1 db loss in signal level was observed. The results were rather drastic as the tape was moved closer to the flux source, as Table I shows. By placing the tape in a steel can, it was possible to get within 2.12 inches of the source before any noticeable increase in print-through was observed.

To minimize the harmful effect of print-through during storage, a new special low-print tape is being produced, with at least 8 db less print-through than standard tape.

Effect of hydrogen sulfide. Several months ago, in a paper entitled "A Cause of Recording-Tape Deterioration,"[4] J. K. Murray noted that tapes exposed to humid hydrogen sulfide for one hour lost as much as 7 db in playback level. Since London "smog" contains some hydrogen sulfide, he recommended air-tight storage.

Similar "smog" conditions exist in various cities throughout the U. S., therefore Mr. Murray's experiment was repeated here. After one month of exposure to humid, concentrated, hydrogen sulfide fumes, no change in the performance of Audiotape could be found. It is believed that some binders have protective properties not present in others.

CONCLUSIONS

To minimize the effects of long-time storage, the following precautionary measures are recommended:

1. Store magnetic tape at temperatures from 70° F. to 75° F., at a relative humidity of 40% to 50% to avoid physical and magnetic distortions.
2. Store the tapes as wound up on the take-up reel. This will insure smooth winds and minimize print-through.
3. Avoid external magnetic fields since they can increase the print-through materially, and even destroy the recorded data.
4. Store tapes in moisture-proof containers, preferably metal cans, and stack "on edge" to minimize reel distortion.
5. Use Mylar base tapes to reduce general physical distortion.
6. Rewind tapes every 6 to 12 months at speeds no greater than 30 ips to relieve the plastic stress. This procedure also shifts the layers so that print-through will not be cumulative.

By following these precautions, magnetic tape can be stored for at least ten years without serious deterioration. Any attempt to predict longer life would be pure speculation at the present state of knowledge.

[3] W. K. Westmijze, *Phillips Res. Rep.*, pp. 148-157, 161-183, 245-269, 343-366 (1953).

[4] J. K. Murray, *Sound Recording and Reprod.*, 4, 318 (1956).

Coincident Sound for Home Movies Provided by Tape Recorders*

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When taped sound must accompany the showing of a motion picture, problems of synchronization arise. This paper describes a simple, widely applicable regulator system for recording such sound, in which a high degree of synchronization is assured.

As the film is run through the projector, the accompanying sound is taped on a half-track tape recorder. An auxiliary head simultaneously records a 60 cps tone derived from the projector power source upon the adjoining track. In playback, this tone, suitably amplified, drives a small auxiliary synchronous motor which, by appropriate gearing, controls the projector speed. Errors which may arise from stretched tape, tape creep, and line frequency variations are thus eliminated. Details of a typical system are presented, together with a description of the modifications which must be made on the tape recorder and the film projector.

INTRODUCTION

HOBBIES OFTEN expand into many side lines, and the hobbyist soon becomes involved in many arts and sciences not normally associated with the basic hobby. One very good example is home movies.

Not too long ago, the ardent home movie enthusiast was content with the production of a film in which the exposure was uniformly good, the sequences interesting and following in a logical order, and where written captions provided supplementary explanations of scenes which were not quite obvious to the audience.

As the art progressed, he added mood music to enhance the enjoyment of the visual presentation. This involved some appreciation of musical moods and the matching of musical selections to the moods depicted by the film. Soon a better appreciation for music was added to the photographic and editing skills.

The early methods for providing a musical background involved the use of dual turntables and disc recordings. These recordings were selected to fit the moods of the picture. Cue sheets were made up to indicate the change of mood in the film, and cue strips were made up for each record to indicate the starting point for each selection and its cut-off or fade-out point. During the course of the film projection, the operator changed records, dissolving one into the other at the proper time and was generally a rather busy person, hoping all the while that no mistakes would be made. Synchronism was no particular problem, since there was in effect a correction every few minutes as the music was changed in accordance with the cues.

Many of the turntable and amplifier systems were home produced, and the home movie maker soon found himself somewhat of an expert in sound systems and electronics as well as in photography and music.

A few individuals have invested in sound cameras and projectors to add a more professional touch to their hobby. While this is a fine way to add synchronized sound to a film, it is not always the most desirable, since editing is difficult, mood music and sound effects cannot be conveniently added, and the equipment is both costly and cumbersome. Add to this the extra cost incurred when film is run at 24 frames instead of 16 frames, which is necessary for even fair fidelity of sound on film reproduction, and the fact that such systems are not generally available for use with 8 mm. film, and it is obvious that sound on film will never enjoy tremendous popularity for home use.

PROBLEMS PRESENTED BY TAPE

The natural trend is toward the use of tape recordings as an auxiliary sound track to accompany home movies. Here we have a means for recording all the background music for a given film, but with the disadvantage that the cues will not usually fall at the proper point due to vagaries in synchronism between the projector and the tape recorder. Even where both machines are driven by synchronous motors, a lack of coincidence exists between the tape and film due to slippage of the tape on the capstan, commonly known as "tape creep." This difficulty has been alleviated to some

* Paper presented at the Fifth Annual West Coast Convention of the Audio Engineering Society, Los Angeles, February 7, 1957.

† Senior Member Technical Staff.

extent by the appearance of magnetic tape with striped backing. When this tape is used, the recorder is positioned so that flashes of light from the projector gate fall upon the tape; the projector speed is then manually adjusted until the tape appears to stand still, indicating synchronism between the tape and the film. With this system, adequate coincidence between the sound and the picture can be maintained by continual speed monitoring on the part of the operator.

Good home movie entertainment is realized only when appropriate sound effects, dialogue, and background music accompany the film in perfect coincidence with the action appearing on the screen. To be really popular, a system which accomplishes this must be equally applicable to 8 mm. and to 16 mm. films. Furthermore, the production of the sound track must not entail either a sizable financial investment or special training, and the total equipment required must be reasonable in size and weight.

As previously indicated, the improvement of low cost tape recorders to their present performance levels has opened up interesting possibilities for separate sound tracks for home use with any size film. Various methods have been proposed for maintaining some approach to adequate synchronism between the film and the tape. None of these has been completely automatic however, and all have usually required essentially the full undivided attention of the operator to produce satisfactory results.

DESCRIPTION OF SYSTEM

The system described in the following paragraphs is equally applicable to all film sizes and frame speeds, results in a sound track capable of rendering as high a fidelity of reproduction as is desired, provides accurate synchronism between the visual and aural records without the need for constant operator supervision, does not involve reprocessing of the picture film, is relatively inexpensive and straight forward, and, in addition, provides for a sound track that can be produced satisfactorily by a novice. Although the final system is rather simple, it is the result of more than fifteen years of work, and is by far the least involved of any of the many methods developed for adding synchronized sound to home movies.

RECORDING SYSTEM

In essence, the system consists of a conventional half track tape recorder to which has been added an auxiliary record/playback head, an amplifier capable of delivering 10 watts of power at a frequency of 60 cps from the output of the auxiliary head, and a small synchronous motor mechanically linked to a standard motion picture projector. Note that this synchronous motor is an auxiliary motor for the purpose of speed control and does not replace the projector drive motor.

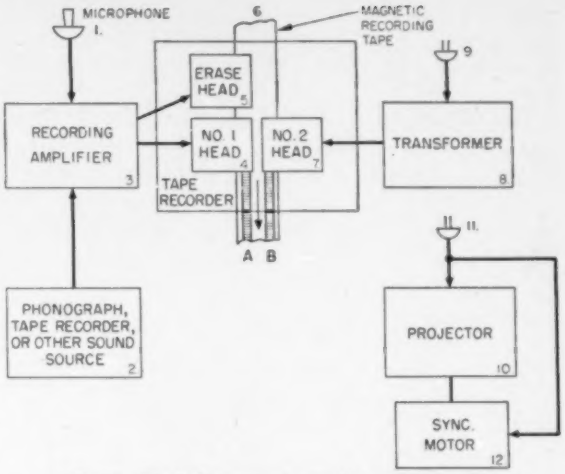


FIG. 1. Block diagram of recording arrangement.

This synchronized sound system is best described by reference to Figs. 1 and 2. In Fig. 1, the functional elements of the recording system are indicated in a block diagram. Two sources of sound, a microphone (1) and a phonograph or tape recorder (2) are indicated. It is anticipated that the musical background and sound effects will be either disc or tape recordings, and that the microphone will be used for adding the descriptive dialogue. The recording amplifier (3) is arranged with the proper mixing circuits to permit the operator to select or mix the various sounds to produce the desired effect. The output of the recording amplifier is applied to the No. 1 recording head (4) which produces a magnetic sound track (A) on the tape (6) while the erase head (5) is energized by conventional supersonic erase and bias signals.

The No. 2 head (7) indicated in Fig. 1 is an auxiliary

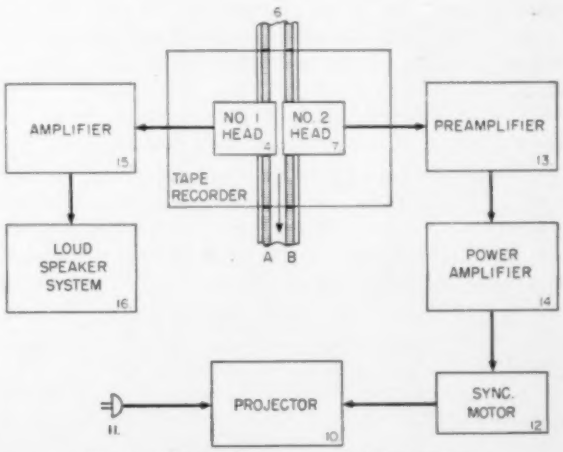


FIG. 2. Block diagram of reproducing system.

record/playback head so positioned that the normally unused half of the tape (B) passes over its pole faces. During the recording process a 60 cycle tone at a level of 6.3 volts is applied to this auxiliary head, producing a corresponding magnetic recording (B) on the tape. For purposes of illustration, this tone is shown derived from the ac power connection (9) through a step down transformer (8).

Also in Fig. 1, the projector (10) and the synchronous motor (12) are powered from another ac line connection (11).

In practice, the recording amplifier (3) is a normal part of the tape recorder, and the step down transformer (8) is the transformer which provides power for the cathode heaters of the tubes. The only modifications are the addition of the auxiliary head (7) and a switch which connects this head to the 6.3 v ac source during the recording process, and to the synchronizing amplifier during playback.

From the foregoing, it will be understood that during the recording process, the speed of the projector is controlled by the frequency of the power line, a sample of which is simultaneously recorded on the tape.

REPRODUCING SYSTEM

The functional parts of the reproducing system are shown in Fig. 2. This again is a block diagram for the purpose of illustration and the various blocks shown are not necessarily separate units.

In operation, the magnetic elements of the sound track (A) on the tape will induce a voltage in the playback head (4) which is amplified by a power amplifier (15) to the proper level to drive the loudspeaker system (16). Simultaneously as the synchronizing half track (B) passes the auxiliary head (7), a 60 cycle ac voltage is induced. This is applied to a preamplifier (13) and then to a power amplifier (14) which controls the speed of the projector (10) through the synchronous motor (12). The power for the projector drive motor and for the projection lamp is supplied through a conventional power connector (11).

The speed of the projector which was controlled by the 60 cycle power line frequency during the recording of the sound track is, during playback, controlled by the 60 cycle tone derived from the synchronizing track on the tape. Any slight variation in frequency arising from tape creep or any other variation in tape speed will be immediately passed on to the projector, thus maintaining complete coincidence between the tape and the film. Since any change in tape speed will introduce a corresponding change in film speed, it is a logical consequence that the synchronism between the reproduced sound and projected picture will be maintained to substantially the same degree as when recorded.

PROCEDURE FOR SYNCHRONIZATION

The exact synchronism between film and sound track presupposed among other requirements a definite starting point for the tape with respect to the film. This is accomplished by marking the leader of the film with a strip of colored pressure sensitive tape. A bit of splicing tape on the back of the magnetic tape provides a corresponding starting mark for the sound track. When all is in readiness, the projector is started and the film loop watched carefully. When the colored tape flashes around the loop, the tape recorder is started, and thenceforth controls the speed of the projector through the medium of the synchronizing tone as previously described.

If complete coincidence[1] is required, as when synchronizing lip sounds with a closeup of a person speaking, it will be necessary to drive the camera with a synchronous motor, and to simultaneously record an ac signal from the same power source. In other words, the camera and the recorder must both be driven from a common ac source, which may be a power line, a mobile converter, or any other suitable source. For most purposes, however, the accompanying sound may be dubbed in later and, while good synchronism between the sound and the action on the film is necessary, absolute coincidence is not essential.

TYPICAL EXAMPLE

The details of the system will vary somewhat, depending upon the type of equipment used. Since it is the purpose of this paper to suggest a suitable system for general use we will deal in generalities and show only one specific embodiment.

The basic elements are a conventional projector, preferably of the type designed for projecting silent films at 16 frames per second, a tape recorder capable of yielding the fidelity of sound desired, an auxiliary amplifier capable of delivering 10 watts of power at 60 cps from the output of a standard tape recording head, a small instrument-type synchronous motor (such as a Bodine Type KYC26) and an auxiliary tape recording head.

The auxiliary recording head is mounted on the tape recorder at any convenient point where the normally unused half of the tape is accessible. Generally, it is possible to modify the tape recorder switch slightly, so that it will perform the additional switching functions which the use of this auxiliary head introduces. It is often possible to add a preamplifier for the synchronizing tone.

The synchronous motor is mounted on the projector in such manner that the film will be projected at 16 frames per second when operated at synchronous speed.

The method of mounting the synchronous motor will depend upon the projector used. Most projectors are equipped with a hand knob for use in checking the threading of the

[1] A trained critical observer can sense as little as one frame out of synchronism. An ordinary observer may tolerate as many as two or three.

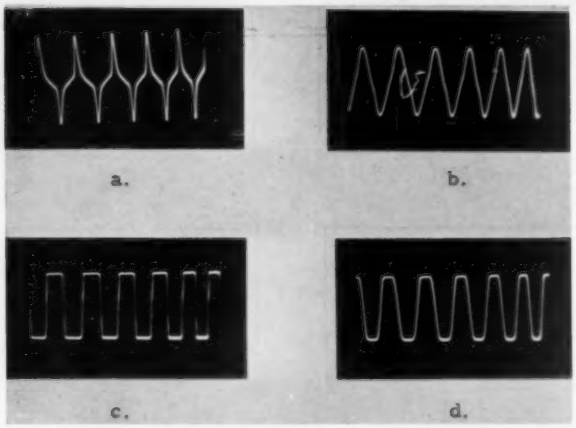


FIG. 3. Waveshape at the output of the auxiliary head, on playback (a) without compensation, (b) with 10 mf capacitor across head, (c) output with limiting in the amplifier, but no capacitor, (d) as in (c) but with a capacitor.

film through the machine. This knob rotates at one revolution per frame, which means that its supporting shaft rotates at 16 revolutions per second. This shaft provides a convenient point for coupling to the synchronous motor and since the motor shaft rotates at a speed of 30 rps at synchronous speed, a gear ratio of 16 : 30 will be required.

A convenient gear combination results from the use of standard commercially available gears such as Boston Gear Co. 48 pitch, ⅛ inch face gears, using a 32 tooth gear on the motor and a 60 tooth gear on the projector. The use of one fiber or nylon gear with one metal gear will reduce gear noise, although gear noise has not been a problem with properly aligned gears.

The synchronizing amplifier may be any conventional amplifier capable of delivering the required power, or it may be a special amplifier with amplitude limiting, which thereby provides constant output to the synchronous motor. An amplifier using push-pull 6V6 or 6L6 tubes in the output stage appears to be about right for the job. The output transformer should have a 500 ohm output winding. While this does not exactly match the impedance of the motor, it is a practical value that represents an excellent design choice. The actual impedance of the motor is about 1000 ohms.

If substantial stray magnetic fields are present in the tape recorder, 60 cycle power line pickup may occur in the auxiliary head; this appears as a slow beat in the output signal. The effect of such stray fields may be minimized by incorporating limiting in the synchronizing amplifier. Several methods are available, the simplest is to introduce poor regulation in the output amplifier stage by the use of high impedance in the grid circuits. Adjustments of the amplifier should be such that the output to the motor will be between 110 and 130 volts with the motor operating normally. Since the motor represents an inductive load, a two microfarad capacitor across the amplifier output is used for power factor correction. This will also modify the square waveform produced by the limiting action, if limiting is used.

The tape is magnetically saturated on each half cycle of the synchronizing tone, no supersonic bias being employed.

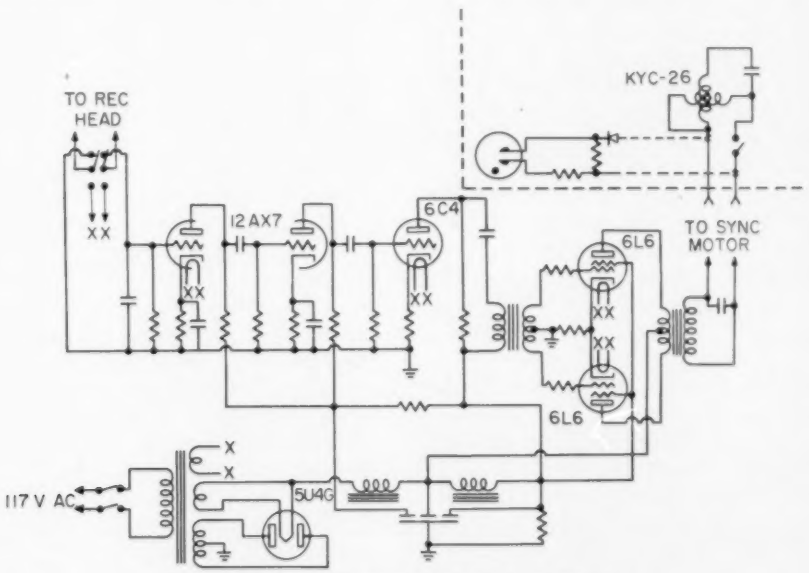
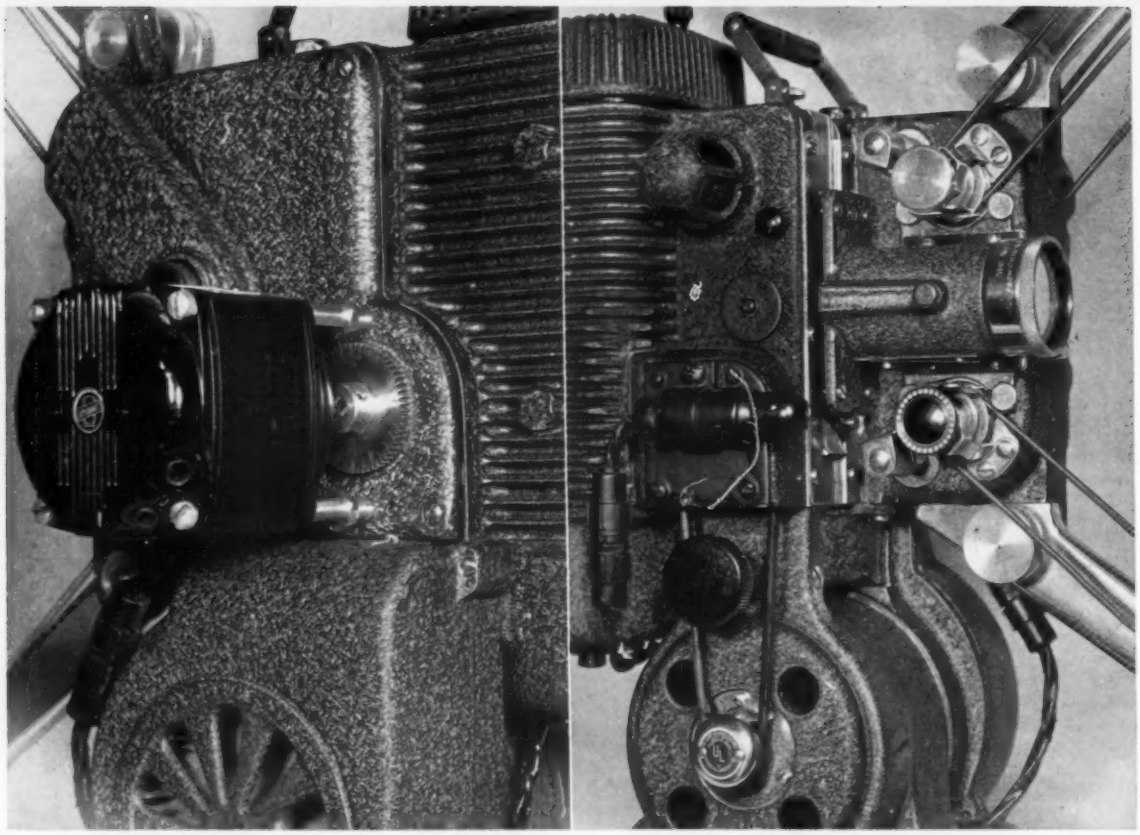


FIG. 4. Circuit diagram for playback amplifier.



a *b*

FIG. 5. Film projector modifications. *a*. Method of mounting synchronous motor. *b*. shows location of strobe points to permit visual monitoring of synchronization.

This provides for a more constant output of the synchronizing tone and at the same time performs the function of completely erasing any previous recording, greatly simplifying the entire system.

On playback, the output voltage from the head is in the form of pulses. The saturated recording method results in alternate blocks or sections of the tape being magnetized as north and south poles. No change in flux occurs except at the point where the polarization changes take place. The output waveform consisting of alternate positive and negative spikes is shown in Fig. 3a. This waveform may be rounded out appreciably by resonating the head at the approximate frequency of the synchronizing tone. A capacitance of 8 to 10 mfd across the head is usually sufficient, and produces the waveform shown in Fig. 3b. The output waveform of an amplifier incorporating limiting is shown in Fig. 3c. This waveform, as modified by the power factor correction capacitor is shown in Fig. 3d, and while it departs appreciably from a sine wave, it has no adverse effect on the operation of the synchronous motor. The amplifier which produced the waveforms shown in Fig. 3 is shown schematically in Fig. 4.

In operation, the synchronous motor exerts a far greater control torque when acting as a brake than when adding torque to the projector drive. The normal projector drive motor is therefore adjusted to operate the projector at a speed slightly in excess of 16 frames per second. The synchronous motor then acts to hold the speed down to precisely 16 frames per second without instability due to speed hunting.

One method of mounting the synchronous motor to the projector is shown in Fig. 5a. In this instance, the motor is mounted directly to the projector gear housing, using studs with an offset hole in one end. Rotation of these studs provides a slight lateral movement of the motor for adjusting the gear mesh.

It would be comforting to know that the projector speed is being controlled by the applied synchronizing tone. This

assurance is easily obtained by the use of a strobe system consisting of a small neon lamp and 32 equally spaced holes drilled near the edge of the film takeup sprocket and filled with white paint as shown in Fig. 5b. The neon lamp is excited by the voltage applied to the synchronous motor.

Tape recorders usually have two inputs, one for a microphone and one for a higher level input such as from a phonograph pickup or a radio receiver. If these two inputs can be used simultaneously or if a mixer is included, a convenient setup results for sound track recording.

Tape recorders designed for recording and reproducing binaural sound require no modification for use in this coincident sound system. The sound track is recorded and reproduced on one channel, while the synchronizing tone is recorded and reproduced on the remaining channel.

A great many sounds are available on pre-recorded phonograph discs. With a good selection of sound effects records and a suitable library of mood music, it is possible to arrange very satisfactory sound tracks for most travelogue type films. A dual turntable and a mixer/fader to permit a smooth transition from one record to the other is a worth-while accessory.

Like any other hobby, one may keep adding accessories, all of which may be considered useful. For instance, a record cutter is a handy device, permitting special sound effects to be recorded. Also, the complete sound track may be made up on discs, and later transferred to tape in the proper sequence. This offers the possibility of reworking each three minute section of the sound track until it is perfect.

With proper cues, coincidence may be maintained, since there is a correction at the start of each record, and each record can be made precisely by the careful timing of each sequence, using a stop watch.

In any case, the final sound track is recorded with the projector operating and controlled from the power line, and with the power line frequency being recorded on the tape for subsequent use as a synchronizing tone. As the projection of the film progresses, appropriate mood music, sound effects, and commentary are recorded. Thereafter, when the film is projected with the projector speed controlled by the tape, the sound will be coincident with the picture to substantially the same extent that it was when recorded, provided the tape recorder is started at the proper instant. So far, the variations in starting time have never produced a noticeable synchronism error between sound and sight, nor has there been a single case of the loss of synchronism during the two years that this system has been in use.

CONCLUSION

The coincident sound system, (the term I have used to describe this arrangement), provides a means for adding sound to any size film desired, provides for the desired fidelity of sound reproduction, permits the use of a film speed of 16 frames per second or any other, is relatively simple and easy to operate, is relatively inexpensive, and provides a means for post-recording sound after the film is edited, without further processing of the film. It fills a long felt need for a system with the versatility required to satisfy many of the needs of amateur and professional alike.

THE AUTHOR

James N. Whitaker is a senior member of the technical staff of Hughes Aircraft Company. His present position is that of Head, Primary Standards and Instrument Maintenance. His technical and professional career includes radio development, maintenance and repair, U.S.N., 1925-1927; Radio Corporation of America research and development, photoradio apparatus, central office equipment and TV systems, 1927-1940; Senior Research Engineer, Federal Telephone and Radio Corporation, high-frequency transmitter research and development, 1940-1941; Senior Engineer, Hammarlund Manufacturing Company, Engineer in Charge, Transmitter Division, 1941-1947; Radio Receptor Company, Engineering Administration, Administrative Engineer, 1947-1950; Hughes Aircraft Company, R. and D. Laboratories, Staff and Services, 1950 to date.

Mr. Whitaker has had more than 90 patents awarded in electronics and allied fields. He is the author of some 25 technical articles in the IRE Proceedings, RCA Review and other publications.

He is a Senior Member of the IRE and was cited during World War II for contributions to the development of countermeasures equipments.

JOURNAL REPRINT

The Editor takes pleasure in reprinting in the pages to follow a paper which, in his opinion, represents the best recent summary of the present state of magnetic recording.

The scope of this paper is quite broad; the authors, who are recognized authorities in this subject, have begun with the basic physical principles and have developed the working equations which are essential to the designer. The mechanical and magnetic principles involved are analyzed in detail and the directions which further work must take are indicated. Together with the paper which they list as Reference 1 (whose co-author is our Western Vice-President), this paper should constitute a most convenient reference for everyone who must employ magnetic recording. The numerous entries in the Bibliography further enhance its value.

Those members planning to attend the forthcoming Convention will be interested to learn that this paper is scheduled to be read at the session on Magnetic Tape Devices.

The Society gratefully acknowledges receiving the permission of the Institution of Electrical Engineers to reproduce this paper in its entirety. It originally appeared in its Proceedings of March 1957.

A Survey of Factors Limiting the Performance of Magnetic Recording Systems

E. D. Daniel, M.A., P. E. Axon, O.B.E., M.Sc., Ph.D., *Associate Members*,
and W. T. Frost, *Graduate*

SUMMARY

Various elements of a magnetic recording system, such as the heads, the tape and the tape transport mechanism, cause departures from the 'ideal' performance of the system, due either to the physical properties of the materials of which they are composed or to the limitations of the accuracy to which they can be made. Some of the effects depend fundamentally only on signal frequency and others only on recorded wavelength. The paper examines the nature and magnitude of the various departures and discusses the improved properties required in the various elements if the ideal performance is to be more closely approached.

(1) INTRODUCTION

In a recent paper[1] Selsted and Snyder discussed some of the limitations of existing magnetic recording techniques and the influence of the magnetic medium upon them. It is the purpose of the present paper to examine elements such as heads, recording media and tape transport systems, which govern the performance of a recorder, rather more closely and so to indicate the difficulties and requirements in various types of application. Fairly detailed treatment is given of some factors which have, hitherto, not been widely discussed. Various factors will be considered in the context of the recording and reproducing processes and with reference to frequency effects (i.e. those depending fundamentally only on signal frequency) and wavelength effects (i.e. those depending fundamentally on recorded wavelength). Frequency and wavelength effects may exist independently or together, depending on the frequency range and recording speed in any particular application. It should be assumed that the paper relates to a tape system, unless otherwise stated, although most of the effects described will also be present, in a more or less exaggerated form, when recording on magnetic drums or discs.

(2) FUNDAMENTAL PROPERTIES OF MAGNETIC RECORDING

(2.1) The Idealized System

A diagrammatic representation of a tape recording and reproducing system is given in Fig. 1A, and a more detailed view of a head is given in Fig. 1B. Let the recording head be fed with a signal current I varying sinusoidally with time at a frequency f. If the core is of infinite permeability, the peak value of the field strength created within the gap is given by

$$\hat{H}_x = (4\pi N'/b')\hat{I} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where b' is the length of the gap and N' is the number of turns on the coil. It will be assumed that this field strength also exists just above the gap, where the tape is moved across the head at a constant speed v. Then, provided that the transmit time b'/v of the tape over the gap is small compared with $1/f$, eqn. (1) represents the strength of a recording field which remains substantially unidirectional and single-valued as a given element traverses the gap. Assuming, further, that the characteristic relating the remanent intensity of magnetization and the field applied to the coating is linearized by some means, it is possible to write

$$\hat{M}_x = \eta \hat{H}_x \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

for the intensity of magnetization in an element of tape after it has left the gap, where η may be termed the 'tape sensitivity'. From eqns. (1) and (2),

$$\hat{M}_x = (4\pi N'\eta/b')\hat{I} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

It is now established practice to define the strength of a recorded signal in terms of 'surface induction', B_y, the mean magnetic induction normal to the surface of the tape in free space. If, as will be assumed in this Section, the tape thickness c is very small and the tape width w is very large compared with the recorded wavelength λ, $\hat{B}_y$ is given closely by[2]

$$\hat{B}_y = (4\pi^2 c/\lambda)\hat{M}_x \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

provided that the permeability of the tape is not much greater

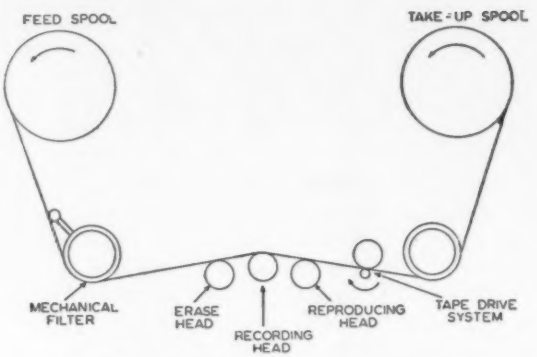


Fig. 1A.—Conventional layout of magnetic-tape recorder.

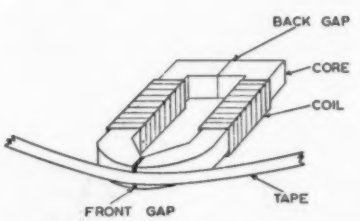


Fig. 1B.—Structure of conventional magnetic head.

Written contributions on papers published without being read at meetings are invited for consideration with a view to publication.

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than unity. From eqns. (3) and (4), the 'recording response' of the ideal system is given by

$$\alpha_i = \hat{B}_y/\hat{I} = 16\pi^3 N'\eta c/b'\lambda \quad . \quad . \quad . \quad . \quad (5)$$

Thus the recording response of the ideal system is inversely proportional to wavelength, or rises at 6 dB per octave with signal frequency.

To reproduce the signal, the tape is passed at the same speed, v, over a head similar to that used for recording, and a sinusoidally varying flux of the form $\Phi = \hat{\Phi} \sin 2\pi ft$ is established in the core which will be assumed to have negligible reluctance compared with that of the gap b. Peak flux will occur when a half-wavelength of tape bridges the gap in such a way that the flux entering each pole piece is additive. Provided that the length of the pole pieces is sufficiently great and $b \ll \lambda$, the peak value of flux is, in fact, equal to the flux emanating from the half-wavelength of tape, so that, integrating B_y between appropriate limits,

$$\hat{\Phi} = w\lambda\hat{B}_y/\pi \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

The varying flux induces in a coil of N turns wound on the head an e.m.f. V of peak value given by

$$\hat{V} = 2\pi fN\hat{\Phi} = (2\pi Nv/\lambda)\hat{\Phi} \quad . \quad . \quad . \quad . \quad (7)$$

From eqns. (6) and (7), the 'reproducing response' of the ideal system is given by

$$\beta_i = \hat{V}/\hat{B}_y = 2Nvw \quad . \quad . \quad . \quad . \quad . \quad (8)$$

which is therefore independent of wavelength or signal frequency.

The 'overall response' is equal to the product of the recording and reproducing responses, and therefore should be proportional to frequency in the ideal case.

(2.2) Use of H.F. Bias

The linearity assumed in the relation between the magnetization of the recording medium and magnetizing field strength is only approximately true in practice over a limited range of unidirectional field strengths. Below this range the remanent intensity of magnetization tends to be proportional to the square of the applied field strength, and above this range it changes little with field strength as saturation is approached.

The approximately linear portion can be utilized in recording a limited range of alternating signal amplitudes it an appropriate value of 'd.c. bias' is fed to the recording head together with the signal current. A method which gives lower basic noise, and a better linearity of response over a greater range of signal amplitudes, is to replace the direct by an alternating current of similar peak magnitude and of frequency in excess of (preferably many times greater than) the highest signal frequency. No detailed explanation of the process of h.f. biasing will be attempted, but a comment on the implications of certain of its properties will be of value in discussing various phenomena in later Sections of the paper. Westmijze[3] has pointed out that the use of h.f. bias in the recording process is analogous to the method of anhysteretic magnetization discussed by Steinhaus and Gumlich.[4] In this method a linear and anhysteretic relation between remanent intensity of magnetization and unidirectional field strength applied to a specimen is obtained by superimposing on each value of unidirectional field an alternating field of high amplitude and then gradually reducing this amplitude to zero. The maximum amplitude of the alternating field is found to be unimportant, provided that it is greater than a certain value, and this is explained by making the following assumption: the final magnetic state of the specimen depends solely upon the instantaneous value of the unidirectional field when the alternating field has been reduced to a certain critical value.

The similarity of this method to the use of h.f. bias in the recording head is obvious if, for example, the longitudinal field distribution of the recording head is considered. This is such that the field strength is a maximum at the centre of the gap and decreases smoothly to zero on either side of it. Thus each element of moving tape is subjected to a maximum h.f.-bias field strength at the centre of the recording-head gap and to a gradually decreasing bias field as it leaves the gap.

In magnetic recording, however, it is observed that the recorded level falls, instead of remaining constant, as the h.f. bias current in the head is increased beyond a certain value. However, in the conventional recording head the instantaneous strength of the signal field, as well as that of the bias field, falls to zero as an element of tape leaves the precincts of the recording-head gap. Thus, when the bias current is excessive, the critical h.f. bias field strength, H_c, may be situated well beyond the trailing edge of the recording gap, where the instantaneous signal field is below the value within the gap, and the recorded level will correspond to this lower signal field.

An assumption made in the discussion of the ideal system is that the recording field is single-valued. The concept of a critical bias implies that this assumption is also valid in the practical case, since, using h.f. bias, the only effective signal field is that existing at the point where the critical bias field is located. If no h.f. bias is used, or the bias current fed to the recording head is too small, the recording field is no longer single-valued, particularly when the gap length is large compared with the wavelength. Under these conditions the magnetization of an element of tape depends not only upon the value of signal field at the critical point near the trailing edge of the gap, but upon the whole of its 'magnetic history' in traversing the gap.[5] As discussed later this can lead to effects of great complication requiring a quite separate explanation.

(3) RESPONSE AS A FUNCTION OF WAVELENGTH

(3.1) Factors Governing the Reproducing Response

(3.1.1) Gap Length.

In deducing the reproducing response [see eqn. (8)] of the ideal system it was assumed that the gap length of the reproducing head was infinitesimal. If a finite gap length is considered it has been shown[3, 6, 7] that the response is approximately given by

$$\hat{V}/\hat{B}_y = 2Nvw(\lambda/\pi b) \sin(\pi b/\lambda) \quad . \quad . \quad . \quad (9)$$

which reduces to eqn. (8) provided that $b \ll \lambda$. Within the range $b < \lambda$ eqn. (9) may be replaced by a more accurate expression, established both theoretically[3, 8] and empirically,[7]

$$\hat{V}/\hat{B}_y = 2Nvw(\lambda/\pi b) \sin(\pi b_e/\lambda) \quad . \quad . \quad . \quad (10)$$

where b_e, the 'effective gap length', is equal to the wavelength at which the first extinction is found to occur and is approximately given by $b_e = 1{\cdot}15b$.

Both eqns. (9) and (10) involve an assumption that all the reluctance of the head is contained in the gap. In practice, however, the core may have appreciable reluctance. Moreover, in order to obtain a narrow, well-defined gap at the front, a head core is usually manufactured in two halves, which are clamped or stuck together, so that a significant gap [Fig. 1B] may exist in the rear of the head. Under these conditions the reproducing response is obtained by multiplying eqn. (10) by the ratio of the front-gap reluctance S_b to the total reluctance S of the head, where

$$\frac{S_b}{S} = \frac{b/A_b}{b/A_b + l/\mu A + a/A} \quad . \quad . \quad . \quad . \quad (11)$$

and a is the length of the rear gap, A_b is the area of the front gap, A is the area of the core and rear gap and l is the length of the core of permeability μ. This factor determines the ratio of flux taking the useful path linking the coil to that taking the unwanted path across the front gap.

It is evident that the length of the front gap of a reproducing head must be chosen with two conflicting requirements in mind: the gap must be small enough to resolve the shortest wavelength, but large enough for adequate sensitivity to be achieved using practicable core materials and core dimensions. The rear gap should be made as small as possible (zero if interleaving of laminations is possible) except in the infrequent cases where reducing h.f. core losses (see Section 5) may be more important than maintaining high sensitivity. Table 1 gives the values of gap length b required to produce 6 dB loss at various frequencies and tape speeds, together with the corresponding sensitivity factor S_b/S. The figures illustrate the precision required in the manufacture of heads for short-wavelength work. In case (*c*) nearly all the reluctance is in the core, and of every hundred lines of flux entering the head, only about seven have a useful effect in the coils. It would be desirable to reduce considerably the reluctance around this core by reducing its length and increasing its permeability. However, in practice, a reduction of core reluctance is not easy, for in h.f. recording, ferrites with low h.f. losses, and hence low permeability, may have to be used. A more promising approach is to increase the taper at the pole tips of the head. For instance, if A_b/A is reduced to 1/10, the sensitivity in (*c*) is increased to 0·22.

Table 1

Example	Description	Tape speed	f	A_b/A	l	μ	a	b	S_b/S
		in/sec			in		mil	mil	
(*a*)	Audio frequency (laminated Mumetal)	15	15 kc/s	2/5	2	20000	0 (interleaving)	0·53	0·93
(*b*)	High frequency (ferrite) ..	100	250 kc/s	2/5	1	800	0·01 (butt joint)	0·21	0·29
(*c*)	Video frequency (ferrite) ..	200	3 Mc/s	2/5	1	800	0·01 (butt joint)	0·035	0·065

The longest wavelength that can be reproduced is still, however, limited by the overall length of the head. If only comparatively low frequencies are of interest, the core size can sometimes be increased. This is not always desirable or possible, especially when the effects of core size on head sensitivity (Section 3.1.1) or h.f. losses (Section 5) are important. In these cases a method of extending the long-wavelength response is to add high-permeability flanges to the head as shown in Fig. 2(*c*).

Finally, it should be mentioned that secondary-gap effects may sometimes be attributable to other causes.[9] At very long wavelengths, approximately expressed by multiplying the response by the factor[3]

$$1 - 0{\cdot}205\,\frac{\cos\left[\pi(D/\lambda + 1/6)\right]}{(D/\lambda)^{2/3}} \quad . \quad . \quad . \quad (12)$$

The calculated l.f. response of a head of this type is indicated by curve (i) of Fig. 3.

The undulations in the response are normally undesirable and are reduced by the more usual configuration of head shown in Fig. 2(*b*), in which the edges of the head are separated from the tape by a distance q. Very approximately the l.f. response of this head is obtained by modifying the factor (12) by a separation factor (Section 3.1.4) to give

$$1 - 0{\cdot}205\exp\left(-2\pi q/\lambda\right)\frac{\cos\left[\pi(D/\lambda + 1/6)\right]}{(D/\lambda)^{2/3}} \quad . \quad (13)$$

When $q > D/2$ the response approaches the smooth curve (ii) of Fig. 3.

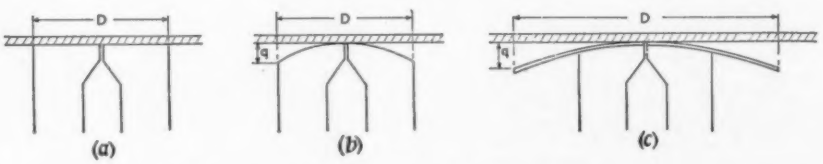

Fig. 2.—Plan views of three possible head configurations.

(3.1.2) Overall Dimensions of the Head.

Expressions (9) and (10) for the reproducing response apply only as long as the pole pieces of the head are capable of collecting all the flux available from a half-wavelength of tape in the peak-output condition. When D, the overall dimension of the head in the direction of tape travel, is less than $\lambda/2$, only a fraction $2D/\lambda$ of the available flux is collected. The extreme l.f. response thus tends to fall with decreasing frequency at a rate of 6 dB per octave. When the extremities of the head are too sharply defined in the neighbourhood of the tape [Fig. 2(*a*)], interference effects, commonly called 'secondary-gap' effects, arise. Provided that λ is not greater than about $3D$ the secondary-gap effect is

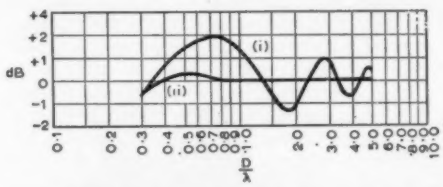

Fig. 3.—Calculated low-frequency response curves of reproducing heads.

(i) Response of reproducing head of the type shown in Fig. 2(*a*).
(ii) Response of reproducing head of the type shown in Fig. 2(*b*).

lengths, tape flux need not necessarily pass through the front surface to link with the head coils but may enter the coils by other paths. In some cases careful attention must be given to points such as the disposition of the coils and the design of screening boxes if such effects are to be minimized.

(3.1.3) Gap Misalignments.

The reproducing head will not work at maximum efficiency at any wavelength unless both edges of its gap are correctly aligned with the trailing edge of the recording gap. The word 'alignment' is not the happiest description of this requirement for three edges to be parallel, but it has now become familiar in this context. If the edges of the reproducing gap are parallel but at a small angle θ to the trailing edge of the recording gap, the reproducing response β_0 is approximately given by[7, 10]

$$\beta_0/\beta_i = (\lambda/\pi w\theta)\sin(\pi w\theta/\lambda) \quad . \quad . \quad . \quad . \quad (14)$$

where β_i is the response obtained with correct alignment ($\theta = 0$). The effect of misalignment is thus analogous to gap loss and can give rise to cyclic amplitude and phase variations in the response corresponding to an effective gap length $w\theta$.

At very short wavelengths the alignment requirements become critical. For instance, if the alignment loss is not to exceed 3 dB, the requirements for $\frac{1}{4}$ in tape are as follows:

(*a*) 15 kc/s, 15 in/sec: $\theta < 0{\cdot}1°$
(*b*) 250 kc/s, 100 in/sec: $\theta < 0{\cdot}04°$
(*c*) 3 Mc/s, 200 in/sec: $\theta < 0{\cdot}007°$

The accuracy of alignment which can be achieved, even with accurately fixed or adjustable head mountings, is limited by the degree to which the edges of the gap may be neither straight nor parallel. These errors have been discussed in detail elsewhere.[7] In addition, however, misalignment may occur in guiding the tape across the heads.[1] The tolerance in the width of $\frac{1}{4}$ in tape is normally $+0$, -6 mils, so that if two guides on either side of a head are situated, say, 2 in apart, a misalignment of 0·34° can exist without allowing any positive clearance in the guides at all. This would give rise to variations in head output from a maximum (at correct alignment) to zero in all the examples given above. Choice of guide spacing with reference to the variations in the tape width is obviously important.

(3.1.4) Separation between Head and Tape.

So far it has been assumed that the surfaces of the head and tape are in perfect contact at the front gap. However, if they are separated by a distance d, the reproducing response becomes[11] β_d, where

$$\beta_d/\beta_i = \exp(-2\pi d/\lambda) \quad . \quad . \quad . \quad . \quad (15)$$

The loss in decibels is therefore proportional to separation, and for a separation equal to a wavelength it is equal to 54·5 dB. The following examples serve to illustrate the importance of the effect:

(*a*) 15 kc/s, 15 in/sec: 5·5 dB per 0·1 mil.
(*b*) 250 kc/s, 100 in/sec: 13·6 dB per 0·1 mil.
(*c*) 3 Mc/s, 200 in/sec: 81·5 dB per 0·1 mil.

These figures indicate the great care that must be taken in the finishing of heads for short-wavelength work, so that the effective separation is reduced to a minimum. Also, of course, adequate pressure between head and tape must be provided either by a suitable combination of tape tension and lap or (less desirably) by means of pressure pads.

In some systems, such as high-speed storage drums, the heads and recording medium work out of contact to avoid wear. It is apparent that the short-wavelength performance of such devices is bound to be greatly limited by separation even of a value that would be thought extremely small in general engineering terms.

(3.2) Factors Governing the Recording Response

(3.2.1) Tape Thickness.

In many applications the shorter wavelengths encountered may be comparable with, and often less than, the thickness of the magnetic coating on the tape. This causes a departure from the ideal performance which, physically, is closely associated with the reproducing process and the exponential nature of the separation loss. When recorded level is defined in terms of surface induction, however, the effect of an appreciable tape thickness must be considered part of the recording process and the recording response is modified[11] from the ideal value α_i to a value α_c, where

$$\alpha_c/\alpha_i = (\lambda/2\pi c)[1 - \exp(-2\pi c/\lambda)] \quad . \quad . \quad . \quad (16)$$

assuming the magnetization at all wavelengths to be uniformly distributed throughout the cross-section of the magnetic coating.

At long wavelengths $\alpha_c/\alpha_i \simeq 1$ and the response approximates to the ideal which rises at 6 dB per octave with signal frequency. At very short wavelengths, however, $\alpha_c/\alpha_i \simeq \lambda/2\pi c$, implying a 6 dB per octave loss with increasing signal frequency and a consequent flattening of the observed h.f. response. For a uniformly magnetized tape of coating thickness 0·5 mil the calculated differences between the actual and ideal recorded levels at (*a*) 15 kc/s, 15 in/sec, (*b*) 250 kc/s, 100 in/sec and (*c*) 3 Mc/s, 200 in/sec amount to 10, 18 and 33·5 dB, respectively.

In effect, the surface induction at long wavelengths is established by substantially equal contributions from all layers of the magnetized coating, but the surface induction at short wavelengths is almost entirely due to a thin layer near the surface. When recording in a restricted range of short wavelengths, such as occur in some carrier systems, it may therefore be possible to reduce the coating thickness without affecting the recorded level. This may result in economy in the cost of tape and an increase in playing time for a given spool diameter.

(3.2.2) Self-Demagnetization in the Tape.

In addition to the useful external field a magnetic field must also exist within the recorded tape. In general, the internal field is in opposition to the magnetization creating it and may cause a reduction in the intensity of this magnetization and a corresponding reduction in surface induction.

In a recorded tape, the magnetization and demagnetizing field may have very different distributions through the depth of the tape, and a precise calculation of the self-demagnetization loss cannot easily be made. An indication of the effect has, however, been obtained[2] by calculating the mean value of the coefficient of self-demagnetization throughout the tape. For a tape magnetized uniformly in the longitudinal direction the loss is found to be negligibly small at long wavelengths, but to increase as the wavelength decreases to a limiting value $1/\mu_t$, where μ_t is the permeability of the coating, which seldom exceeds four in the commonly used materials.

In practice, the true self-demagnetization loss at short wavelengths will be considerably less than is indicated by this simple treatment. For instance:

(i) The magnetization may not all be in the longitudinal direction but may have an appreciable component perpendicular to the tape surface, the self-demagnetization of which is confined largely to long wavelengths.[3]
(ii) The longitudinal demagnetizing field is not constant throughout the depth but is much lower near the surface. This is important at short wavelengths where the useful magnetization may be confined to a surface layer.
(iii) A high-permeability reproducing-head core should reduce

the coefficient of longitudinal self-demagnetization very nearly to zero.[3] Thus, on reproduction, the estimated loss should be considerably reduced.

The last consideration provides experimental evidence of the magnitude of the self-demagnetization loss. If this were serious the recording response of a system measured by means of a conventional reproducing head and a non-magnetic conductor head[7] should be markedly different. In fact, using normal tapes, the responses are substantially the same.[12]

Many early papers attributed the major part of the h.f. loss in the magnetic recording response to self-demagnetization and specified high coercivity as the controlling magnetic property in obtaining a good h.f. response. It now appears that these conclusions were inaccurate: self-demagnetization probably contributes only a small part of the total loss, and the relevant magnetic property is the permeability, rather than the coercivity, of the tape material.

(3.2.3) Non-Uniform Recording Field.

So far, it has been assumed that the recording field is uniformly distributed throughout the depth of the tape. In most cases, however, the recording field strength H will decrease appreciably with distance y from the surface of the head. If H_0 is the strength of the field within the gap, the maximum strength H_x of the longitudinal field outside the gap is approximately given by[2, 13]

$$H_x/H_0 = (2/\pi) \arctan (b'/2y) \quad . \quad . \quad . \quad (17)$$

It follows from eqn. (17) that a gap length b', small compared with the tape thickness c, will lead to a marked decrease in the signal and bias field strengths through the tape, but for other reasons, to be given in the following Sections, it is undesirable to make the gap length very large. Often b' is made approximately equal to the tape thickness, normally 0·5 mil, but the longitudinal field strength at the base of the coating will, even so, be less than one-third of that at the surface.

The decrease of the signal field strength through the depth of the tape is less important than the decrease of the bias field strength, for the latter makes it impossible to bias correctly the whole of the coating. With serious non-uniformity of field, two extreme cases arise as follows:

(*a*) The bias may be adjusted so that the outer layers are correctly biased. In this case the inner layers may be grossly under-biased so that the recording on them is very non-linear, and, since the signal field strength has also fallen, of low level. This will not greatly affect short wavelength work, where the useful magnetization is confined to the surface layers, but it may greatly detract from the performance at long wavelengths ($\lambda > c$).

(*b*) The bias may be adjusted so that the inner layers are correctly biased. In this case the outer layers may be grossly over-biased, leading not so much to distortion in these layers as to a reduction in their intensity of magnetization. The effect is contrary to the previous case in that a greater loss will now occur at short wavelengths for which the outer layers are relied upon for the major contribution to surface induction. It will explain, in part, the fact that short wavelengths are more easily over-biased than long wavelengths, particularly when the tape thickness is large compared with the gap length of the recording head.[2] Over-biasing is further discussed in Section 3.2.4.

To summarize, the recording gap length should be as large as is permitted by the considerations to be discussed in Sections 3.2.4 and 3.2.5. Only if attention is strictly confined to very short wavelengths will a short gap length be entirely advantageous.

(3.2.4) Rate of Extinction of Recording Field.

In discussing h.f. bias in Section 2.3 it was suggested that, in conditions of adequate biasing, the final remanent magnetization of an element of tape leaving the recording head is established at the point where the bias field strength has fallen to a critical value H_c. This might indeed be precisely the case for an element of tape consisting of a single particle or magnetic domain. In general, however, all the particles in the coating will not be identical in form and cannot be expected to require identical values* of H_c. Indeed, as pointed out by Westmijze,[3] if there were a unique value of critical field the sensitivity/bias curve should rise vertically to its maximum value instead of rising, in practice, with a finite (although steep) slope.

This modification of the hypothesis will not materially affect the linearizing action of the bias. It will, however, affect its second attribute, namely the creation of conditions in which the recording signal field experienced by a given element of tape can be regarded as single-valued. Thus if the values of H_c required by the domains in an element of tape are distributed between H_2 and H_1, recording in the element must take place over a distance ξ in which the bias field strength falls from H_2 to H_1. Ignoring the fall in instantaneous signal field strength over this distance, the effect is obviously analogous to an aperture loss of the form

$$\alpha_\xi/\alpha_i = (\lambda/\pi\xi) \sin (\pi\xi/\lambda) \quad . \quad . \quad . \quad . \quad (18)$$

which will have no appreciable effect on the recording response at long wavelengths, but will cause a serious loss when λ becomes comparable with ξ. In practice, of course, the signal field strength will fall to the same extent as the bias field strength over the critical range, and the distribution of H_c may be complex. Nevertheless, it is of interest that series of minima can be observed in the recording response at short wavelengths when high bias levels are used. These minima appear to be unrelated to known gap phenomena, and their position is found to depend very much upon bias level.

The distance ξ will depend upon the rate of extinction of the recording field, and if this could be made instantaneous ξ would be zero. On the other hand, if the decay of field were very slow compared with the period of the signal, the combined signal and bias recording fields might act simply as an erasing field and the tape would emerge from the recording head in a neutral condition. In practice, therefore, the rate of extinction should be made as high as possible—a conclusion supported by the experiments of Muckenhirn.[15] Even with very short gap lengths, however, the rate may still be significant, and a substantial part of the h.f. loss of biased systems can probably be attributed to this 'critical range' effect. Alternatively, of course, the distance ξ is reduced when the range $(H_2 - H_1)$ of critical fields required by the coating particles becomes smaller. If all particles required the same critical field, H_c, the rate of extinction of the recording field would be unimportant and no h.f. loss should result from it.

A secondary effect of considerable importance is that the distance ξ will also depend upon bias current. This arises because the decay of the bias field on leaving the gap is not uniform. If the bias current in the head is increased, the limits of the critical range are moved further away from the gap and are spaced further apart on a more gradually sloping part of the bias-field decay curve. This may account for the fact that short wavelengths are found to be more easily over-biased than long wavelengths, even when recording gaps substantially greater than the tape thickness are used and the effects noted in Section 3.2.3 cannot play a large part. In practice, the short-wavelength over-biasing phenomenon often imposes a serious limitation on the performance of biased systems owing to the compromise adjustment which has to be made to avoid serious h.f. loss on the one hand and l.f. insensitivity and distortion on the other.

(3.2.5) Interference Effects in the Recording Gap.

If good linearity of response is required the use of h.f. bias in recording is essential. The discussion in the preceding two Sec-

* The theory of magnetization in heterogeneous alloys developed by Stoner and Wohlforth has been shown by Osmond[14] to be applicable to tape materials. The existence of critical fields is then readily explained in terms of particle-shape anisotropy.

tions indicates, however, that there are also certain disadvantages, particularly when short wavelengths are to be recorded. In applications where a good response at very short wavelengths is a more important requirement than linearity, such as computer stores, an unbiased system is frequently employed.

It has been shown,[5] however, that the recording field affecting the tape when h.f. bias is absent is not single-valued, and serious interference effects may then occur in the recording gap. These give rise to undulations in the recording-frequency characteristic which are related to the finite length of the recording gap, with minima occurring when the gap length b' is approximately equal to $3\lambda/4$, $7\lambda/4$, etc. In pulse recording work the phase-distortion aspect of these undulations may be of greater importance than the amplitude variations. It has also been shown[5] that the effect of adding and increasing bias is gradually to eliminate the minima, but, unfortunately, they cannot always be entirely removed before an appreciable over-biasing of the shortest wavelength occurs owing to the secondary effects discussed in Sections 3.2.3 and 3.2.4. The interference phenomena in the recording process may therefore also be significant in systems in which, perhaps to avoid h.f. over-biasing, too low an h.f. bias is used in conjunction with an appreciable gap length.

A conclusion of considerable importance to draw from this discussion is that when, for various reasons, a recording system is to be used with little or no h.f. bias, the gap length of the recording head should be small enough for the condition, say, $b' < \lambda_s/2$ to obtain, where λ_s is the shortest wavelength to be recorded.

(3.2.6) Separation between Head and Tape.

The surface of the tape may be intentionally or accidentally separated from the surface of the recording head for reasons similar to those described in the reproducing head case but with results which although more complex, are generally less serious. Two principal effects can be envisaged as follows:

(i) Separation will decrease the strength of both the signal and bias fields and cause a general loss in recording response. The effect will be most marked if, when in contact, the bias field strength is only just sufficient to give maximum sensitivity.

(ii) Separation will cause a lower rate of extinction of the recording field, since the leakage flux is more widely spread over planes removed some distance from the gap. This, from the arguments of Section 3.2.4, may cause a loss at shorter wavelengths, but the loss is normally very small compared with that arising in an equivalent separation from the reproducing head.

(4) AMPLITUDE AND SPEED FLUCTUATIONS

(4.1) Effect of Amplitude Fluctuations

In practice, the e.m.f. in the reproducing head contains components of noise, forming part of the phenomenon known as 'modulation noise', owing to undesired amplitude fluctuations which are superimposed on the input signal in the recording and reproducing processes. A typical distribution of the instantaneous amplitudes in the (nominally constant) envelope of a 10 kc/s tone, recorded and reproduced at 15 in/sec on a production tape of average quality, is shown in Fig. 4. Analysis of these fluctuations indicates that they are largely random so that they contribute a true noise voltage to the input signal and so reduce the signal/noise ratio. In the following Sections some consideration will be given to the origins of these fluctuations in order to assess how far they may be reduced by careful design and manufacture of the components of the system.

(4.2) Factors Causing Amplitude Fluctuations

(4.2.1) Particle Nature of the Coating.

In most modern systems the recording medium consists of small particles of a suitable magnetic oxide of iron which are

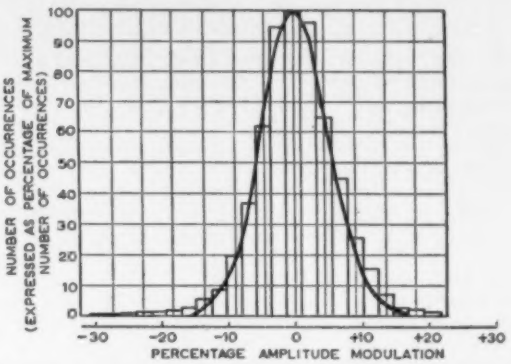

Fig. 4.—Distribution of amplitudes in modulation envelope of recorded 10 kc/s tone.
Period of observation: 10 sec.

mixed with a suitable binding agent and coated on to a plastic tape or other surface, as required. The medium may therefore consist of crystals which vary, according to the manufacturing process, in size, shape and orientation[14] and in separation from one another.[16] The uniformity of distribution and size of the particles, and of their orientation, is, of course, vastly increased in modern tapes compared with the products of a few years ago. Nevertheless it remains true that the variation of magnetization within any one recorded wavelength must occur in a series of discrete steps, the magnitude of which depends on uniformity in the factors noted above. The size of single domains imposes an ultimate limit on short-wavelength recording, for, clearly, no frequency corresponding to a half-wavelength shorter than the average size of domain can have a sensible effect on the medium. This ultimate limit cannot be achieved, however, whilst the particles, even if single domains, are separated by some finite distance owing to the presence of the binding agent. The practical limit is then larger by a factor depending on the average separation of particles, i.e. the 'packing factor'. A random variation in packing factor will create an even greater limitation, since the random variation of amplitude which it imposes on the recorded signal appears as noise in the reproduced output. These coating variations will particularly affect the signal/noise ratio in the short-wavelength region, in which only a surface layer of the tape is employed. The effect at longer wavelengths should be less severe if the lack of uniformity in size, packing and orientation is the same at all depths within the coating, for the greater the number of layers contributing to the output the less will be the relative effect of a variation of signal in any one of them.

(4.2.2) Irregularities in the Surface of Backing.

Another noise contribution of this type occurs when the surface of the backing on which the medium is supported is irregular. Lack of smoothness in the backing creates a gross variation in the dispersion of the particles at the base of the coating, and this will assume importance when the under layers are significant in the recording and reproducing processes. This is the case at long wavelengths if the signal and bias fields from the recording head are such as to establish an appreciable magnetization at the base of the coating. This effect accounts for the comparatively high modulation noise which occurs in tapes with paper backing, compared to those with plastic backing, the fibrous nature of paper making it difficult to attain the same degree of surface smoothness that can exist on a plastic material.

(4.2.3) Variations of Contact between Head and Tape.

The level of signal appearing at the terminals of the reproducing head has been shown to depend on the effective separation of the recording medium from the heads in the recording and reproducing process. In practice, undesired changes in the separation of the tape from the heads will occur for several reasons and create another source of modulation noise.

The lack of uniformity in the coating, previously discussed, also implies a lack of perfect flatness at the surface, so that the effective separation of the tape from the heads must vary in a manner depending on the surface variations. Extreme cases of the latter can lead to an almost complete disappearance (a 'drop-out') of the signal. These variations may be reduced by suitable polishing of the tape surface after manufacture. Similar fluctuations may also arise when tape debris, which may be created by rough head or guide surfaces, is carried over the heads. In this connection, a build-up of static charge on the tape surface, which retains debris or attracts dust, should be avoided.

Tape-width variations may also cause fluctuations when, in order to obtain high accuracy of alignment, the clearance in the guides is reduced too much. If a portion of tape occurs which is outside the tolerance allowed, it will bend, and be lifted from the head surface, in passing through the guides. Inaccuracies in the driving system, which vary the tape tension, will also vary the effective separation of head and tape.

(4.3) Effect of Speed Fluctuations

In practice, even in a well-designed system, the tape speed is never perfectly correct for an appreciable period, and the reproduced signal contains the effects, in the form of frequency modulations, of errors in both the recording and reproducing processes. The errors are attributable to mechanical imperfections of the drive system and to interactions between the moving tape and the transport system. Certain well-defined frequencies of modulation may be present, but it has been shown elsewhere[17] that a large random element may also be observed. As such, the speed changes make an addition of modulation noise to the signal and reduce the ability of the system to provide accurately timed information when required. In the next few Sections the origin of these speed changes will be examined and measures which may be taken to reduce them will be briefly discussed.

(4.4) Factors Causing Speed Fluctuations

(4.4.1) Tape Transport System.

In the tape-recording system illustrated in Fig. 1A the drive is obtained from a rotating capstan against which the tape is held by a spring-loaded rubber idler. This system is widely employed, and it is unnecessary to describe here the manufacturing accuracy and measures required if adequate freedom from speed fluctuations is to be obtained. In many cases, however, insufficient attention is paid to the spooling system, although it is obvious that any sudden fluctuations in spooling torques must vary the tension and the velocity of the tape over the heads. Fluctuations of this kind arise if there are eccentricities in the spools, if the tape comes into accidental contact with the sides of the spool or if there are inaccuracies in any pulleys which guide the tape to the heads. The tape over the heads is, of course, in some degree isolated by the capstan system from sudden torque changes in the take-up-spool system. The same is not true of the feed-spool system, however, and some other measure, such as the mechanical filter indicated in Fig. 1A, may be necessary. Where high mean accuracy is required it is possible to control the torque of the spooling motors by a servo system actuated by tension indicators which are placed in contact with the tape adjacent to the spools.[18] Comparative isolation from both take-up and feed spools is also possible in an alternative drive system[19] illustrated in Fig. 5. The tape is driven by the capstan at two points, A and B, and passes over a pulley C between them, the recording and reproducing heads being mounted at convenient points inside the loop so formed.

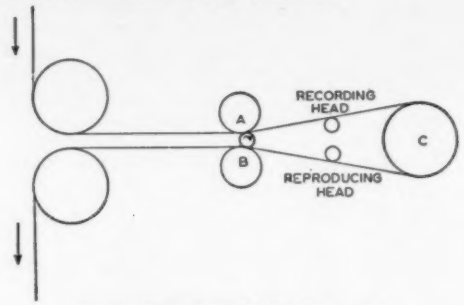

Fig. 5.—'Double-pinch' driving system.

(4.4.2) Interaction between Tape and Transport System.

The small variations of width which may exist along the length of the tape are also important as a source of speed fluctuations. Completely accurate guiding requires the guide width to be identical to the nominal width of the tape, but, in practice, some tolerance must be allowed. When a length of tape occurs which is wider than the guide the frictional forces between the edges of the tape and guide become large. On the other hand, when a length of tape occurs which is narrower than the guide the edge frictional forces are confined to one edge only or may even be absent altogether. If there is random variation in the width of the tape an appreciable random component must be present in the frictional forces. When the length of tape over the heads is not isolated from these forces its velocity must vary accordingly.

In the conventional form of static guide the surface of either the backing or the coating also comes into contact with the face of the guide and another set of frictional forces occurs. A similar set is also generated as the tape passes each head. Random surface conditions on either coating or backing (Section 4.2.3) will vary these forces to introduce another random element into the system. Surface friction in the guides will be eliminated if they are so designed and positioned that the tape comes into contact with them only at its edges or if the guides take the form of pulleys which are driven by the tape.

Surface friction is also significant in the origination of another distinctive set of higher-frequency speed fluctuations, which may be observed under critical conditions. These fluctuations, which have been investigated by Werner,[20] result from a longitudinal oscillation of the tape generated by static elements such as the heads, the excitation being provided by the frictional forces. If no slip is occurring at, for example, the guide pulleys situated before the heads and the driving point on the capstan which follows them, these elements have zero speed relative to the tape and they constitute bridges or nodes between which the oscillations are propagated. If s is the distance between the nodes, the frequency of the oscillation is given by $f = (1/2s)\sqrt{(E/\rho)}$, where E is the modulus of elasticity and ρ is the density of the tape. In practice, the frequency of the oscillations is found to lie between 1 and 3 kc/s, and their amplitude varies with the coefficient of friction of the tape and the tape tension, the latter determining the pressure on the heads and hence the frictional forces set up. The effect is therefore particularly large in machines in which contact between the heads and tape is maintained by pressure pads. The

amplitude will be reduced in a conventional system if the following requirements are observed:

(*a*) The tape tension is reduced as far as possible, consistent with adequate contact.
(*b*) The coefficient of friction of the tape is made as small as possible.
(*c*) Fixed guides touch the tape only at its edges.
(*d*) The head surfaces are extremely well polished.

These factors cannot usually be adjusted to eliminate the oscillations completely, but the traces which remain may be further reduced by 'loading' the tape, at convenient points between the heads, with further pulleys on which no slip occurs.[20] It is also beneficial to mount the heads near the drive system and to make the distance between heads as small as possible. These latter measures tend to generate the oscillations at higher frequencies at which they are more severely attenuated. When loading pulleys are introduced they must be of high accuracy, in order to ensure that they do not introduce periodic fluctuations on their own account.

(5) LOSSES IN THE HEAD CORE

(5.1) Nature of Core Losses

The sensitivity of a reproducing head is proportional (Section 3.1.1) to the ratio of front-gap reluctance, S_b, to total reluctance, S. The sensitivity of a recording or an erasing head may be defined in terms of the field strength produced in the gap for a given current in the coils, and is then proportional to $1/S$. Thus, for all types of heads, the ratio of the sensitivity σ_f at a frequency f to the sensitivity σ_0 at zero or very low frequencies is given by

$$\frac{\sigma_f}{\sigma_0} = \frac{S_0}{S_f} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (19)$$

This assumes that the reluctance of the gap remains constant but that the total reluctance of the head increases from S_0 to S_f as the frequency is raised from zero to the value f. Such an increase is attributable to the fact that an increasing amount of energy is absorbed in eddy-current, hysteresis and 'residual' losses in the core as the frequency is raised. These losses are accompanied by a lag in phase and can be described by considering the effective permeability of the core to change from a real value μ_0 at zero frequency to a complex quantity μ_f at a frequency f, where

$$\mu_f = \mu' - j\mu'' \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (20)$$

If the head has a front-gap length b, a rear-gap length a, a core length l, and a cross-sectional area A throughout, eqn. (19) can be written

$$\frac{\sigma_f}{\sigma_0} = \frac{b + a + l/\mu_0}{b + a + l/\mu_f} = \frac{\gamma + 1/\mu_0}{\gamma + 1/\mu_f} \quad . \quad . \quad . \quad (21)$$

where

$$\gamma = \frac{b + a}{l} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (22)$$

The core is often tapered towards the front gap when the cross-sectional area A_b of the front gap is considerably less than A. This can be taken into account by replacing b by bA/A_b in eqn. (22).

Substituting for μ_f in eqn. (21) and rationalizing,

$$\left|\frac{\sigma_f}{\sigma_0}\right| = \frac{\gamma\mu_0 + 1}{\mu_0}\left[\frac{(\mu')^2 + (\mu'')^2}{(\gamma\mu' + 1)^2 + (\gamma\mu'')^2}\right]^{1/2} \quad . \quad . \quad (23)$$

and the angle Φ of the phase lag is given by

$$\tan\Phi = \mu''/[\gamma(\mu'^2 + \mu''^2) + \mu'] \quad . \quad . \quad . \quad (24)$$

From eqn. (23) the head sensitivity remains substantially constant provided that $\gamma\mu' \gg 1$, i.e. the reluctance of the core is always small compared with that of the gaps. In general, therefore, the effect of core losses can be minimized by (*a*) making the front gap length as large as possible without causing severe interference effects at the shortest wavelength, (*b*) introducing an appreciable gap in the rear of the head, if absolute sensitivity requirements allow it, and (*c*) making the core as short as possible and of a material of high permeability and low loss over the required frequency range. The effect of core losses is reduced by (*b*) at the expense of a reduction in absolute sensitivity equivalent to multiplying the response when $a = 0$ by the factor

$$\frac{b + l/\mu_0}{a + b + l/\mu_0} \quad . \quad . \quad . \quad . \quad . \quad . \quad (25)$$

Loss of sensitivity in recording heads can be offset by increased recording currents, and here the larger rear gap may be well worth while, for, in addition to reducing the effect of core losses, it also tends to reduce the effects of non-linearity in the core. In reproducing heads, however, absolute sensitivity is usually of overriding importance and a large rear gap is unacceptable. The overall sensitivity is then proportional to the product of eqns. (23) and (11).

(5.2) Measurement of Core Losses

Two methods of measuring the effect of core losses on head performance are in common use, particularly in connection with frequency-characteristic standardization. The first, and perhaps the more direct, method relies upon separating the losses that fundamentally depend on frequency from those that fundamentally depend on wavelength by taking measurements of overall response at a variety of tape speeds. In the second method an alternating flux is induced in the head from a small conducting loop or coil placed near the front gap, and core losses are determined by measuring the departure of the e.m.f. generated in the head coil from a 6 dB per octave law.

In many cases, however, it is convenient to assess the core losses from bridge measurements of the impedance of the head at various frequencies. When L_0 and R_0 are the series inductance and resistance at zero frequency and L_f and R_f are the effective values measured at a frequency $f = \omega/2\pi$, the effect of core losses on head sensitivity is given by

$$\left|\frac{\sigma_f}{\sigma_0}\right| = \left|\frac{S_0}{S_f}\right| = \frac{L_f}{L_0}\left(1 + \frac{1}{Q_f^2}\right)^{1/2} \quad . \quad . \quad . \quad . \quad (26)$$

where

$$Q_f = \frac{\omega L_f}{R_f - R_0} \quad \text{and} \quad \tan\Phi = \frac{1}{Q_f}$$

(5.3) Losses in Laminated Alloy Cores

The most frequently used core materials, particularly in the lower-frequency ranges, are nickel–iron alloys. These materials have extremely high permeabilities but comparatively low resistivities, so that normally they are laminated to avoid excessive eddy-current losses. For a lamination thickness δ and resistivity ρ the eddy-current loss gives rise to a complex permeability[21] in which

$$\left.\begin{aligned} \mu' &= \frac{\mu_0}{\psi}\frac{\sinh\psi + \sin\psi}{\cosh\psi + \cos\psi} \\ \mu'' &= \frac{\mu_0}{\psi}\frac{\sinh\psi - \sin\psi}{\cosh\psi + \cos\psi} \\ \psi &= 2\pi\delta\sqrt{\frac{\mu_0 f}{\rho}} \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (27)$$

In most cases the eddy-current loss will be much greater than the hysteresis or residual loss, even when considering recording or erasing heads in which the maximum flux density may be high. Eqns. (27) may therefore be used in conjunction with eqn. (23) to give a close estimation of the head sensitivity loss using a laminated material. For values of ψ greater than 5, $\mu' \simeq \mu'' \simeq \mu_0/\psi$ and eqn. (23) becomes

$$\left|\frac{\sigma_f}{\sigma_0}\right| = \frac{(\gamma\mu_0 + 1)\sqrt{2}}{[(\gamma\mu_0 + \psi)^2 + (\gamma\mu_0)^2]^{1/2}} \quad . \quad . \quad . \quad (28)$$

Thus when $\psi \gg \gamma\mu_0$ the sensitivity of a laminated head will tend to fall at a rate proportional to the square root of frequency and the phase lag will tend towards 45°.

As an indication of the lamination thickness required, consider a possible head in which $b = 0{\cdot}3$ mil, $l = 1{\cdot}5$ in and the halves of the core are interleaved to avoid a rear gap. Let the laminations be such that $\rho = 40$ microhm-cm and $\mu_0 = 10000$, so that $\gamma\mu_0 = 2$. Then if an eddy-current loss of 6 dB is acceptable at 16 kc/s the lamination thickness must not exceed 6 mils, and for the same loss at 600 kc/s it must not exceed 1 mil.

In practice the improvement obtained with a lamination thickness less than 5 mils will seldom be as great as that expected from simple theory. Additional losses, possibly due to skin effects, become significant and the laminations are difficult to prepare. Mechanical working after the final heat treatment, a certain amount of which is usually unavoidable in head manufacture, may also cause large local reductions in the effective permeability.

(5.4) Losses in Ferrite Cores

Eddy-current losses can be reduced to negligible proportions if the head core is made of a ferrite material, the resistivity of which may be a million or more times that of the common alloys. Several grades are available covering a wide range of permeability, residual loss coefficient, maximum flux density and coercivity. In general, the permeabilities and maximum flux densities are much lower, and the coercivities are much higher, than those of magnetic alloys.

In reproducing heads the desirable properties of the core are high permeability and small residual loss. When information is available on the variation of the components of the complex permeability with frequency the most suitable material for a particular reproducing head can be chosen by calculating sensitivity/frequency curves from eqn. (23). It is usually found that ferrites of permeability much less than 1000 give an unacceptably poor sensitivity at low frequencies, even though they may have very small losses, so that the number of grades to choose from is limited. With available ferrites of permeability of the order of 1000 it is possible to produce a reproducing head with negligible loss up to a frequency of approximately 1 Mc/s.

The core of a recording head should also have high permeability and low residual loss, but here the hysteresis loss must be considered. Even without bias the flux density in the core may be high enough for hysteresis losses to become appreciable at the higher signal frequencies, and a ferrite of low coercivity should therefore be used. When bias is used the recording head must, in effect, be designed to handle a considerable power at a frequency normally many times greater than the highest signal frequency. Hysteresis effects at the bias frequency can cause excessive losses, which, since ferrites are usually poor thermal conductors, may give rise to over-heating. In extreme cases, when out-of-contact working or high-coercivity tape necessitate very high bias currents, the temperature of the core may rise above the Curie point, which is of the order of 150° C. It may also be found in such cases that the maximum flux density of certain grades of ferrite is inadequate. When bias is necessary and these considerations limit its frequency to a value f_b, the highest signal frequency that can satisfactorily be recorded is also limited to a value f_b/K, where K ought to be at least 3. If K is less than 3 the biasing action becomes less efficient, the signal level falls and non-linearity may be present. Unwanted frequency components may then be generated within the signal band by interaction between signal and bias.

Similar considerations affect the choice of core for the erasing head, in which the frequency must usually be well above the highest signal frequency that could be recorded by the erasing head if it were used as an unbiased recording head.

(6) SOME PROBLEMS OF HEAD CONSTRUCTION

(6.1) Construction of Ferrite Heads

The use of ferrites introduces new problems of construction and finish, some of which are very difficult to solve. Three principal difficulties arise as follows:

(*a*) Ferrites are difficult to mould in small intricate shapes owing to their severe contraction after sintering.
(*b*) They are brittle and difficult to work.
(*c*) The surface finish obtainable is limited by the existence of small holes and fissures in the material.

The first two difficulties can be largely overcome by developing suitable grinding techniques. The third is more difficult to surmount and attempts made so far have not met with a great deal of success. It is, indeed, possible to assemble a ferrite head, polish the front surface, and obtain a finish which looks smooth under the microscope. When the head is used, however, it is inevitably found that the performance rapidly deteriorates; tape dust piles up on the contact surface, and, after cleaning and re-examination, the finish is found to be rough. These findings have been confirmed by other workers.[22]

Until such time as a more suitable ferrite material is developed, a method[23] of overcoming this difficulty which can be made to give satisfactory results consists of facing a ferrite core with a thin sheet of high-permeability alloy. The technique is essentially one of combining the good surface-finish and wearing properties of the alloy with the low core losses of the ferrite. The alloy is cemented to the two halves of the core before the gap faces are polished and the head is assembled. The alloy sheet should, of course, be as thin as possible to avoid eddy-current effects and should be in intimate contact with the core proper to avoid excessive loss in general sensitivity. An advantage of the technique is that, by sharply tapering the ferrite pole-tips below the alloy face and by using an alloy of permeability much greater than that of the ferrite, an effective value of γ can be obtained which is considerably greater than b/l for the ferrite alone.

(6.2) Head Systems for Multi-Track Recording

In some applications of magnetic recording, several signals are required to be recorded simultaneously, and this has led to the development of multi-track systems in which the various input signals are handled by separate pairs of recording and reproducing heads on parallel tracks on the medium. In some arrangements the individual heads are manufactured separately and laid out in echelon formation across the width of the tape or drum. Advantages of this are that direct crosstalk between the various heads is eliminated and the alignment of each reproducing head can be precisely adjusted to match its associated recording head. Difficulties arise, however, when great phase accuracy is required between the various reproduced signals, and complicated mechanical adjustments have then to be provided to make the various head spacings equal and maintain them so under conditions of mechanical movement, tape stretch or temperature change. An

alternative method is to manufacture the heads, with screens between them, in a composite stack and ensure, by a suitable manufacturing process, that all the gaps are in perfect alignment both with respect to one another and to the direction of tape travel. This becomes more difficult as the number of heads in the stack is increased and the permissible time or phase error is decreased. A common method is to manufacture the stack of heads in two halves with respect to a line through the centre of the gaps (e.g. see Reference 24), but little information has been revealed on detailed procedures.

The magnetic screens which are placed between adjacent heads to prevent direct crosstalk do not reduce appreciably the inter-track crosstalk which arises at long wavelengths as flux from one recorded track spreads into adjacent reproducing heads. If the magnitude of this type of crosstalk (which is common to both stack and echelon systems) is unacceptable, the track separation must be increased or a carrier system adopted in which the order of recorded wavelengths is shorter and the spread of flux correspondingly less.[18]

(7) EQUALIZATION OF THE RESPONSE

In general, the overall response, V/I, of a magnetic recorder at first rises, at a rate approximately proportional to frequency, to a maximum and then falls with increasing frequency owing to the combined effect of the various losses detailed in previous Sections. Let it be assumed that the inherent differentiation of the system has been corrected by inserting a suitable integrating stage into the reproducing amplifier. The amplitude/frequency characteristic is then (ignoring very-long-wavelength losses) essentially that of a low-pass network which can theoretically be corrected by inserting the appropriate high-pass network in the chain. The total amplitude correction possible, and the relative amounts which are placed in the recording and reproducing chains, depends on the frequency spectrum of the input signal and the noise and distortion characteristics of the system.

Equalization of phase as well as amplitude may be more difficult, however, depending on the nature of the losses. In so far as the amplitude and phase relationships of these losses are approximately similar to those which occur in linear, passive, electrical networks, their correction, theoretically at any rate, is straightforward. Core losses in the heads can, for example, be corrected in phase and amplitude by comparatively simple methods. Thus, if laminated recording and reproducing heads are used, in which eddy currents cause the major loss, their combined loss is eventually proportional to frequency and the eventual phase lag is 90°, which, fundamentally, can be corrected by means of a simple RC network. Another technique, applicable in simple form to the correction of recording-head core losses, is to apply a negative-feedback voltage, derived from the integrated e.m.f. from a secondary winding on the head, to the input of the recording amplifier. If sufficient gain is inserted in the feedback loop a linear relation between head flux and current can be obtained regardless of core losses. A similar, though more complicated, procedure may be used to correct losses in a reproducing head.

However, the various other losses in the system do not have a parallel in linear passive networks. Thus aperture effects are purely amplitude losses which introduce no distortion of phase, unless the response actually contains a reproducing-gap minimum or recording-gap interference effects are present. Similarly the separation and the tape-thickness losses are attenuations which increase, without any associated phase change, with decreasing wavelength. These losses may be equalized using derivative equalizer techniques[25] in which only even-power derivatives of frequency are involved. In practice, the degree to which the equalization curve required may be approximated is limited by the highest-power derivative with an acceptable signal/noise ratio which is available from the equalizer. The derivative method has the advantage that adjustments can be made while the system is actually operating and, by introducing odd-order derivatives (the first is usually available in the direct output from the reproducing head), correction can be made at the same time for the losses in the head cores and in the associated electrical equipment. It is not easy to carry out phase measurements on recording equipment, owing to the fact that there is a large (indefinitely large on separate record and replay) delay between output and input, and, inevitably, a certain amount of wow and flutter. The only possible techniques are similar to those used on long lines or radio links when the input signal is not available for comparison with the output.

(8) DISCUSSION

The fundamental inefficiency of the conventional system at long wavelengths may be overcome by the adoption of a modulated carrier system which utilizes a band of frequencies, the wavelengths of which lie outside the inefficient region. The severity of the unwanted amplitude modulation which occurs in practice will be increased at the shorter wavelengths of the carrier system, and this may prohibit the use of an amplitude-modulated carrier. This difficulty may be overcome by frequency modulation, which is also the solution when a reduction of the unwanted amplitude modulation in conventional recording is a requirement. Stringent requirements are then imposed, however, on the speed constancy of the system. In all cases the recording speed necessary will be many times that required to record the highest modulating frequency conventionally, so that all carrier systems are less economic in the use of tape. They are, however, inherently more free from the effects of accidental printing, for the wavelengths on the tape are usually much less than that at which optimum printing[26] occurs.

In considering the use of carrier modulation to overcome long-wavelength difficulties it must be remembered that it is not always necessary to adopt a carrier method, and, in some cases, where very low frequencies are involved, a flux-sensitive reproducing head[27, 28] may be used which allows the recording chain, and the tape speed, to remain unchanged.

In general, however, it appears that the most fruitful advance towards greater utility of the magnetic system is an improvement in its high-frequency and short-wavelength performance. Improvement in this respect will extend both direct and carrier recording applications. The developments required are partly of a magnetic and partly of a mechanical nature.

In heads the improvements required are mainly in the core materials. The laminated alloy cores employed for audio frequencies are unsuitable for high frequencies owing to the severity of the eddy-current losses. Although the ferrite cores available are better in this respect, they are inferior in most other respects. First, lower hysteresis and residual losses are desirable to maintain the signal strength at high frequencies and reduce the heat generated. Secondly, much greater mechanical stability and much better machining properties are necessary to allow the manufacture of fine gaps and intimate contact surfaces.

The magnetic properties of the tape coating should be such that a high maximum sensitivity is obtainable at a low bias field, and for short-wavelength applications its various components should require similar values of critical field H_c, to provide permanent magnetization. The coating should possess a high uniformity of distribution and a surface smoothness which gives low friction and good intimacy of contact with the heads. The mechanical properties of the backing are almost equally important: it should be smooth, flexible, free from appreciable stretch and stable under normal variations of temperature and

humidity. The width of the tape should be maintained within the closest tolerances so that the guiding system may be made to the high accuracy required to eliminate alignment errors.

(9) ACKNOWLEDGMENT

The paper is published by permission of the Chief Engineer of the British Broadcasting Corporation.

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You Can Write Better Technical Reports*

JOHN L. KENT†

Consolidated Electrodynamics Corporation, Pasadena, Calif.

This paper is reprinted by permission of the copyright owners with the fond hope that the literary quality of manuscripts submitted to the Editor will be improved. It has probably been read by more engineers than any other article on technical writing published in 1955. Apart from its usefulness to our contributors, we expect that its interest will extend to all our members who must cope with the sometimes disagreeable task of writing reports and papers. The text reprinted here is a portion of a more extended series which has been published in booklet form by C.E.C.

YOU can improve your technical reports by adopting methods used by professional writers. Failure to do so may result in injustice to yourself and to your career.

Since your writing is judged by the same criteria as that of the professional writer, you must use the same methods to get comparable results. Some of these methods are really the writers' "tricks of the trade." One is the use of short sentences.

Long and involved sentences give technically-trained people more trouble than any other single factor. Because of their training and experience chemists, engineers, and other technicians are generally precise. Thus when they sit down to write, they qualify each idea with limiting phrases so that long sentences result. Shortening sentences will help get readability and prevent grammatical errors.

The short sentence is probably the greatest help to understandable writing. It permits spacing of ideas. Ideally, each sentence should be limited to one thought. Very often, however, simple sentences are incapable of communicating complete thoughts.

As sentences become longer, relationships between words become less clear. Such sentences are harder to understand and may require rereading. They often lead to errors in grammar.

There's another reason why technical people in particular should write short sentences. In ordinary writing, shorter words can be substituted to help the reader understand. Generally, technical words cannot be simplified. Short sentences can compensate for this limitation.

During recent years researchers have come up with a "readability formula" or criterion. The formula shows that when average length of sentences runs over 20 words, thoughts become difficult to understand.

Here is a standard in terms of words per average sentence:

Under 10	—Easy to read
15	—Fairly easy
20	—Standard
25	—Difficult
Over 30	—Very difficult

Here is how you can measure the readability of your writing. Pick several blocks of seven sentences at random throughout your manuscript. Average the sentence lengths of each block of seven; then average the average of each block.

Remember this: A sentence of over 25 words generally can be cut into two short ones. After several long sentences, insert a short one to act as a "rest" for the mind. Aim to get more sentences into the easily grasped 10- to 15-word length.

USE SIMPLE WORDS

Because of misplaced deference to convention, many empty, bookish, formalistic, and legalistic words and phrases creep into our speech and writing. Most of them can be called "non-working" words. Cull them and substitute "action" words. Here are a few examples:

* Reprinted with permission from *Technical Writing Tips*. Copyright, 1956 by Consolidated Electrodynamics Corporation, Pasadena, California. Original appeared in *Chemical and Engineering News*, Jan. 31, 1955.

† Chief, Editorial Bureau

Avoid	Use instead
with respect to	for, about
effectuate	carry out
ascertain	find out, learn
for the purpose of	for
in the nature of	like
in view of the fact of	because, since
presently	now
along the line of	like
subsequent to	for, after
avail yourself	use

REMEMBER TO PARAGRAPH

Many technical people are troubled over paragraphing. What should a paragraph include? When do you begin a new paragraph? In modern usage, paragraphs are becoming shorter. In newspapers, for example, almost every sentence is a paragraph.

The first sentence of a good paragraph should be the topic sentence. It should tell the reader what's going to be said in the paragraph. It should also provide a transition (if such is needed) from the preceding paragraph. This topic sentence should be short and direct.

A good paragraph should also have a summarizing sentence which should warn the reader—"this is the end; prepare for another thought or another subject."

The rule of composition on paragraphing is clear. When the thought or subject premise in the topic sentence is exhausted, start a new paragraph. Consideration for the reader may modify this rule somewhat. Written with the reader in mind, paragraphs should do several things:

- Give the reader visual evidence of a break in thought.
- Provide just enough material on each thought, or facet of a subject, not to tire his mind.
- Provide a "hook" for the reader's attention.

Therefore, it is better to over-paragraph. The reader won't object.

After you have written the first draft, edit it with a good dictionary at hand, and perhaps even a book on grammar to resolve doubtful construction.

READ IT OVER

Read your manuscript several times. First read over the entire draft to get the "feel" of it. Does it tell a story simply and concisely? Cut and shorten where possible.

Read it over a second time, looking for bad sentences, lack of topic sentences, and errors in grammar. If time permits, put the manuscript out of sight for a day or two. Then read it a third time before letting it out of your hands.

Paying attention to rules of composition and grammar is not enough. The professional writer soon learns many things that are not taught in college composition courses. You should practice them, too.

For example, have confidence in your writing. You cannot do anything well unless you have confidence in your ability. Also, you must show interest in your writing. A good report is the result of a lot of hard work—and enthusiasm. But most of all, you've got to write if you want to be a good report writer. Writing is something that can be learned only through practice.

WRITING FAULTS TO WATCH

Even a cursory examination of engineer-produced writing reveals that fairly good English is used and that grammatical errors are relatively few. The major faults are in the things the engineer-writer has neglected to consider. The length of the piece, for example. Most articles and reports are "overwritten." If they were planned, they would be much shorter. The usual faults of engineer-produced writing can be grouped under several subheads. Check your writing against this list to improve its readability.

FAILURE TO CONSIDER THE READER

The first rule of writing anything is to ask yourself: "Who is going to read this?" After you have "placed" your reader, you can proceed on the proper level to make him understand what you are about to write. To write well enough to be understood, it is necessary to know that a reader's mind grasps ideas in bits. Therefore, ideas and thoughts in a report or any other technical writing have to be "fed" to the reader in small doses. In any writing this is done through the use of short sentences and the more common words.

LACK OF ORDER

A report is a specialized form of expository writing whose order should be apparent through section headings, subheadings, numbered paragraphs and other means. Reports have become standardized and usually include a title page, an abstract, a table of contents, the body (including introduction, discussion, and conclusion), and the recommendations.

An article, too, has a form. It is not a cutdown report. It's a distinct piece of writing.

Planning the order is part mental, part written. Make an outline. Unless you have such an outline (either firmly decided upon mentally, or actually in writing) your information will not be presented as well as it could be.

NEGATIVISM

Engineers too often use the negative to describe the properties of anything . . . such as "this device is not fragile in

ordinary handling." Why not say "this device withstands ordinary handling." Another negativism found in instruction sheets particularly, is: "Do not fail to remove handle . . . etc." when instruction should be "Remove handle, etc."

WORDINESS

Many technical articles are excessively long because authors fail to edit. Article should be edited so that the final writing is the bare substance with just enough details to carry the story intelligently. This means condensing the pruning, both in the subject included (selective omission), and in the manner of presentation (deliberate conciseness).

JARGON AND CLICHES

Engineers insist on using certain words and phrases which to them have become sacred. Psychologists who study such things have come to the conclusion that engineers like to read cliches such as "on the order of" when they could say "about" because they recognize them as something they themselves do. As one writer put it, "it reminds them of home cooking."

LACK OF "SELL"

Engineers generally don't know how to "put over" an article. Most of the technical articles are uninspired and uninspiring. Often the article is not even a good recital of facts. To get good presentation you must not only get facts down briefly, but so arrange them that the reader can sense that back of the arrangement and presentation was an engineer who knew what he was talking about. Directness, simplicity, and enthusiasm help "put over" an article. People respect a man who knows where he is going. The same thing holds good for an article.

* * * *

Book Review

Die Grundlagen der Akustik (Fundamentals of Acoustics) (In German)

EUGEN SKUDRZYK, Springer-Verlag, Vienna, Austria, 1954, 1084 pages, 450 illustrations, $35.00

This handbook provides a comprehensive treatment of the whole subject of acoustics in the audible range, done with the thoroughness expected of the German school. The author, who had formerly been Professor of Audiofrequency Technique at the Vienna Technische Hochschule, has a long history of research and publication in acoustics. He is presently with The Ordnance Research Laboratory, Pennsylvania State University.

The presentation is uncompromisingly professional, with somewhat more attention to theory than to experimental methods. A knowledge of partial differential equations, complex variables, advanced electric circuit theory and the simpler transcendental functions is necessary for a complete comprehension of the text. However, the results of theory and experiment are compared wherever possible.

A listing of chapter topics is one indication of the scope of the work. Some important ones are: Fourier series, integrals, and the Laplace transformation; derivation of the fundamental equation of the sound field; reflection at the interface between two media; the wave equation in cylindrical coordinates; spherical waves; Huyghens' principle; boundary value problems; radiation from surfaces; equivalent circuits; mechanical systems; acoustical elements; electroacoustic transducers; acoustical impedance; the ear, speech and music; room acoustics and acoustical materials; underwater acoustics; sound in solids; and non-linear effects. The book concludes with a valuable listing of references for each chapter.

The German reads rather easily, especially if the reader is versed in the topic discussed. It is to the worker in the science of acoustics that this book is most likely to appeal, rather than the practicing audio engineer. However, it is a complete compendium of the state of the art (as of 1953), and every engineering library should have a copy.

VINCENT SALMON
Manager, Sonics Section
Stanford Research Institute
Menlo Park, California

NINTH ANNUAL CONVENTION OF THE AUDIO ENGINEERING SOCIETY

Tentative Program

The Ninth Annual Convention of the Audio Engineering Society will be held at the New York Trade Fair Building from Tuesday, October 8th through Saturday, October 12th. The Banquet is scheduled for Thursday evening, the 10th. As was the case last year, the New York High Fidelity Show, sponsored by the Institute of High Fidelity Manufacturers, will exhibit concurrently.

According to Sherman M. Fairchild, Convention Chairman and Executive Vice-President of the Society, more papers will be presented at this Convention than at any previous meeting. Thus far over 60 papers in 17 sessions have been scheduled, necessitating opening the Technical Sessions one day earlier than anticipated. Foreign papers, from England, Holland, Japan, and Brazil, account for ten percent of the program, lending an international aspect to the proceedings. A feature of great interest will be two symposia, with professional panelists: "Test Records for Phono Pickup Measurements" to be presented on Tuesday afternoon and "Stereo Tape Standards" scheduled for Friday evening.

The extraordinary efforts put forth by the Chairman, the respective Subcommittee Chairmen, and the authors, the broad scope and exceptional merit of the papers, and the expected greater attendance this year, give promise of an outstanding Convention.

The tentative schedule of the Technical Sessions is as follows:

Tuesday Morning, October 8

DISC RECORDING AND PLAYBACK

Edward Sorenson, Chairman

Latest Advances in Extra Fine Groove Recording
Dr. Peter C. Goldmark

Cutting Mechanism in Disc Recording
A. Y. C. Tang

PERCEPTION OF WOW

Sheldon I. Wilpon, Chairman

Measurement of Flutter in Magnetic Tape Recording
Roger H. Prager

A Recorder for the Production of Wow Measurement Tape
Jack Bayha

Subjective Discrimination of Pitch and Amplitude Fluctuations in Recording Systems
P. E. Axon and A. Stott

Tuesday Afternoon, October 8

MEASUREMENT OF DISC AND TAPE FREQUENCY RESPONSE

Sheldon I. Wilpon, Chairman

Calibration of Disc Frequency Records
Lincoln Thompson

An Analysis of Tape Noise in a 100 Kilocycle Bandwidth
Robert E. Glendon

Calibration of Disc Recording by Light-Pattern Measurements
P. E. Axon and W. K. E. Geddes

Loopholes in Standard Quality Performance Tests of Magnetic Tape
John M. Leslie, Jr.

Calibration of Test Records by B-Line Patterns
B. B. Bauer

SYMPOSIUM

Test Records for Phono Pickup Measurements

Wednesday Morning, October 9

STUDIO ACOUSTICS AND PSYCHOACOUSTICS

Dr. L. L. Beranek, Chairman

Recent Experiences in Studio Design
L. L. Beranek, J. B. C. Purcell, W. E. Clark, B. G. Watters, W. R. Farrell

Audio Instruments for Physical and Psychological Measurements
J. J. Hanrick

The Psychological Parameters of the Masking Effect as Applied to Sound Recording and Reproduction
John A. Cooley

Basic Considerations in Studio Design
H. V. Munchhausen

AUDIO APPLICATION PROBLEMS

Gordon Mercer, Chairman

Use of Speaker Arrays for Home Installation
Gordon Mercer

Wednesday Afternoon, October 9

ELECTRONIC MUSIC

Professor Otto Luening, Chairman

The Instruments of Experimental Music
Dr. Abraham A. Moles

The Processes of Experimental Music
Professor Vladimir A. Ussachevsky

Musical Composition with a High Speed Digital Computor
L. A. Hiller, Jr. and L. M. Isaacson

Electronic Instrument, Toy, Educational Aid
Leonard E. Geisler

ARTIFICIAL REVERBERATION

John M. Hollywood, Chairman

Some Notes About Artificial Reverberation
Carlos E. R. A. Moura and Sergio Lara Campos

Some Practical Aspects of Magnetic Tape Reverberation Generator Design and Operation
C. J. LeBel

Stereo-Reverberation
R. Vermeulen

Thursday Morning, October 10

TAPE DUPLICATION

Julius Konins, Chairman

Commercial Duplication of Stereo and Monaural Tapes
R. J. Tinkham

Problems and Considerations of Tape Duplicating Production
Julius Konins

AUDIO TRANSISTOR APPLICATIONS

Frank Dukat, Chairman

A Transistorized Preamplifier for Professional Turntables
Harold J. Paz

Transistorized Magnetic and Photoelectric Input Stages for Sound Motion Picture Projectors
S. F. Bushman

A Portable Transistor Music System
Richard S. Burwen

Thursday Afternoon, October 10

MAGNETIC TAPE DEVICES

Walter H. Erikson, Chairman

A Survey of Factors Limiting the Performance of Magnetic Recording Systems
E. D. Daniel, P. E. Axon and W. T. Frost

A Continuously Variable Tape Drive Mechanism for the Investigation of Sound Phenomena
John J. Hanson

Variable Speed Scanning of Recorded Magnetic Tapes
William S. Latham

Design of an Audio Program Selector in a Magnetic Tape Recorder
A. Y. C. Tang

A Continuous Loop Magnetic Tape Cartridge
Bernard A. Cousino and Ralph E. Cousino

Magnetic Tape Noise
Robert A. von Behren

The Finer Structure of Magnetic Tape; Microscopic Studies
Dr. Reuben M. Cares

Mylar Polyester Film and Acetate as Base for Magnetic Recording Tape
D. L. Ormond

Thursday Evening, October 10

ANNUAL BANQUET

Friday Morning, October 11

AES Business Meeting

MICROPHONES AND SPEECH INPUT SYSTEMS

Philip C. Erhorn, Chairman

Variable 'D' Cardioids
Wayne A. Beaverson

Application of the Model 677 Microphone
L. R. Burroughs

A Second Order Gradient Ultra Directional Microphone
Jere W. O'Neill

FM AUDIO RECEPTION

George Maerkle, Chairman

Stereocasting by FM Multiplex Method
William S. Halstead

A Compatible System of Stereo Transmission by FM Multiplex
Murray G. Crosby

Friday Afternoon, October 11

STEREO PROBLEMS

H. E. Roys, Chairman

Artificial Stereophony Using Single Input
Manfred R. Schroeder

Stereophonic Sound with Two Tracks, Three Channels by Means of a Phantom Circuit
Paul W. Klipsch

Stereophonic Sound Reproduction in the Home
Harry F. Olson

The Westrex StereoDisk System
C. C. Davis

Stereophonic Recording Techniques
W. H. Miltenburg

Friday Evening, October 11

SYMPOSIUM

Stereo Tape Standards

Saturday Morning, October 12

SPEAKERS AND SPEAKER ENCLOSURES

John Preston, Chairman

The Fundamentals of Loudspeaker Design
Frank H. Slaymaker

Sound Reenforcing Systems
John E. Volkman

A Wide Range Loudspeaker System
Maurice E. Swift and Albert Katella

Some Observations on Reproduced Sound in an Automobile
B. A. Schwarz and D. E. Brinkerhoff

TURNTABLES AND ARMS

R. E. Carlson, Chairman

Servo-Driven Phono Arm
Jacob Rabinow

A New Viscous Damped Tone Arm Development
Chester A. Snow, Jr.

A New Approach to the High Performance Turntable Problem
Rein Narma and E. P. Skov

Saturday Afternoon, October 12

AMPLIFIERS

Victor Brociner, Chairman

Some Defects in Amplifier Performance Not Covered by Standard Specifications
Norman H. Crowhurst

Mismatch Between Power Amplifiers and Loudspeaker Loads
Daniel von Recklinghausen

New Developments in Output Transformerless Power Amplifiers
J. Rodrigues de Miranda and Dr. J. J. Zaalbergvan Zelst

On the Performance of Loudspeakers Driven by Negative Impedance Amplifiers
R. E. Werner and R. M. Carrell

Two High Power Transistorized Audio Amplifiers
M. B. Herscher

PHONO PICKUPS

Benjamin B. Bauer, Chairman

Phonograph Styli—Their Use and Wear
Barnett A. Edwards

A Manufacturer's Case for the Ceramic Cartridge
Jack Bayha

The High Fidelity User Looks at Pickup Design
Julian D. Hirsch

AES News

Officers and Governors of the Society for the Year 1956-1957

The following Officers and Governors were elected by the Society to serve during the year 1956-1957.

OFFICERS

President: Walter O. Stanton
Pickering & Company, Inc.
309 Woods Ave.
Oceanside, N. Y.

Executive Vice-President: Sherman M. Fairchild
Sherman M. Fairchild and Associates, Inc.
580 Midland Ave.
Yonkers, N. Y.

Central Vice-President: Henry J. Schroeder
Schroeder Sales Company
2309 Prospect Ave.
Cleveland 15, O.

Western Vice-President: Ross H. Snyder
Ampex Corporation
934 Charter St.
Redwood City, Calif.

Secretary: C. J. LeBel
P. O. Box 12, Old Chelsea Station
New York 11, N. Y.

Treasurer: Ralph A. Schlegel
RKO Teleradio Pictures, Inc.
WOR Division
1440 Broadway
New York 18, N. Y.

GOVERNORS

Len Frank
Carnegie Hall Recording Co.
881 Seventh Ave.
New York 19, N. Y.

E. V. B. Kettleman
RCA Victor
155 East 24th St.
New York 10, N. Y.

Clair D. Krepps
95 East Main St.
Bergenfield, N. J.

In addition to the elected members above, the Board consists of the past President:

Richard H. Ranger
Rangertone, Inc.
73 Winthrop St.
Newark 4, N. J.

and the three Governors who will complete their terms of office this year:

Victor Brociner
Brociner Electronics Corporation
344 East 32nd St.
New York 16, N. Y.

C. Robert Fine
Fine Recording, Inc.
118 West 57th St.
New York, N. Y.

Donald J. Plunkett
Capitol Records, Inc.
151 West 46th St.
New York, N. Y.

Appointments to Committees

The Board of Governors have announced the following appointments of members to head the Society's Committees for the year 1956-1957.

Name of Committee	Chairman
Admissions:	E. V. B. Kettleman RCA Victor 155 East 24th St. New York 10, N. Y.
Awards:	Ernest W. Franck 432 Courtland Ave. Glenbrook, Conn.
Convention:	Sherman M. Fairchild 17 East 65th St. New York 21, N. Y.
Employment Register:	E. V. B. Kettleman (above)
Finance:	Victor Brociner Brociner Electronics Corp. 344 East 32nd St. New York 16, N. Y.
Historical:	C. A. Rackey National Broadcasting Co. 30 Rockefeller Plaza New York 20, N. Y.
Laws and Resolutions:	Vincent J. Liebler Columbia Records, Inc. 799 Seventh Ave. New York 19, N. Y.
Lecture Course:	W. H. Offenhauser, Jr. (Temporary) River Road New Canaan, Conn.
Membership:	C. Robert Paulson Ampex Corporation 934 Charter St. Redwood City, Calif.
Nominations:	Richard H. Ranger Rangertone, Inc. 73 Winthrop St. Newark 4, N. J.
Papers Procurement:	Carl E. Warner Michael Todd Co., Inc. 729 Seventh Ave. New York, N. Y.
Publications:	Donald J. Plunkett Capitol Records, Inc. 151 West 46th St. New York, N. Y.

Public Relations: William A. Savory
E.M.I. (U.S.) Ltd.
38 West 48th St.
New York 36, N. Y.

Sections: George P. Petetin
Pickering & Company, Inc.
309 Woods Ave.
Oceanside, N. Y.

Standards: Ruben E. Carlson
Fairchild Recording Equipment Co.
10-40 45th Ave.
Long Island City 1, N. Y.

Proceedings of Our Sections

Los Angeles

Chairman: Chester A. Boggs
Secretary: Pell Kruttschnitt

February 26, 1957

Paper: "Two Channel Stereophonic Production," George Fields and J. C. Baker
Discussion: Demonstrations of stereo tapes and recording conditions.
Business: Results of West Coast Convention and Banquet.

March 26, 1957

Papers: "Mohawk Midgetape Battery-operated Tape Recorder," E. vanLeeuwen
"Quality Control as Related to Custom Recording," P. Kruttschnitt

Japan

Secretary: John H. Nakamura

August 21, 1956

Papers: "Status of Audio in the U. S.," Warren Birkenhead
"Report on Visit to U. S.," Prof. Tsuyoshi Itow

October 5, 1956

Paper: "Report on Visit to Europe and U. S.," Prof. Ryozaburo Taguchi
Business: Discussion on AES activities at coming Audio Fair in Tokyo.

February 8, 1957

Paper: "Recent Trends in the Audio Field in the U. S.," Warren Birkenhead
Discussion: Mr. Birkenhead, who attended the 1956 Annual Convention, also showed sound films of the Japan Section.

February 26, 1957

Paper: "Public Relations and its Significance," Mr. Wesson of Fairchild Publications
General Election Results:
Chairman: J. H. Nakamura
Vice-Chairman: Shozaburo Wada
Secretary: Mishima Itow
Treasurer: Masuo Hayashi
Editor: Saburo Takahashi
Committee: Warren Birkenhead, Ryozaburo Taguchi, Tomio Murata, Yoichi Umehara

April 3, 1957

Discussion: Spring Open Meeting to be held at International House, May 18, 1957. Tentative list of papers was drawn up. Committee members appointed were: Minesaburo Imanishi, Hisagatsu Nakamura, Saburo Takahashi, and Yoichi Umehara. Mr. Birkenhead's proposal to approach U. S. Embassy regarding assistance available to the Japan Section concerning audio engineering information was approved.

Indiana Technical College

Secretary: Donald A. Butterworth

March 19, 1957

Paper: Showing of Bell System films.
Business: New Constitution approved. Announcement of contest for audio papers. A banquet was planned for the May session.

Rensselaer Polytechnic Institute

Secretary: Warren Davis

September 18, 1956

Business: Organizational meeting. Freshmen and new members were welcomed and the purposes and activities of the Society were explained.

February 28, 1957

Paper: "Transistor Amplifiers," Marcian E. Hoff
Business: Appointment of Vincent Vasile as Secretary-Treasurer. Discussed choice of new faculty advisor.

Employment Register

If you are looking for a job in the audio engineering field or are looking for somebody to fill one, you are invited by E. V. B. Kettleman, Chairman of the Employment Register Committee, to submit a brief resume of your requirements. Should you also desire such information to appear in the columns of the JOURNAL, a paragraph in a form suitable for publication should accompany your letter. Address him at RCA Victor Record Division, RCA, 155 East 24th Street, New York 10, N. Y. Correspondence will, of course, be kept confidential.

Replies to the following notices should be addressed to Mr. Kettleman, who will forward them to the respective individuals.

Positions Wanted

J-1. ENGINEER, P.E., E.E., married, with approximately 23 years experience in microphone development, research in precious metals, and transformer development and production, desires a position with a progressive organization. Presently located in N. Y. Metropolitan area. Member AES, IRE, and the Acoustical Society of America.

J-2. RECORDING ENGINEER, British, seeks employment in U.S.A. Prior experience with E.M.I. Familiar with Neumann microphones, Presto and Neumann cutters, most tape recorders including E.M.I. BTR 2 and Ampex stereo. Thoroughly experienced in editing, cutting microgroove masters and stereo-balancing. Familiar with studio techniques such as limiting, equalizing, and back-tracking. Member AES.

J-3. ENGINEER, American presently located in Japan, seeks U.S. employment. Twenty years ultra-practical experience in electronics and audio as designer, technical writer, and technician. Member AES.

Membership Information

(as of June 1, 1957)

New Members

Members

Beyer, Eugen, 107 Bismarck Street, Heilbronn am Neckar, Germany
Brook, Lois A., 2475 Central Park Avenue, Yonkers, N. Y.
Browning, Robert D., c/o RCA, 445 N. Lake Shore Drive, Chicago, Ill.
Chase, Leonard A., 3012 Avenue W, Brooklyn 29, N. Y.
Claras, Carl W., 320 East 21st St., Chicago 16, Ill.
Coulter, Thomas W., 5337 Pagewood Lane, Houston 19, Texas
Crawford, Arthur J., 150 East 79th St., New York 21, N. Y.
Daniels, Joseph L., 47 Meander Lane, Levittown, L. I., N. Y.
Doschek, Anthony, 84 Kingston Ave., Pittsburgh 5, Pa.
Gillespie, James B., 76 Garner St., Buffalo 13, N. Y.
Gspann, Charles J., 736 Sheridan Ave., Roselle, N. J.
Hire, Charles J., 81 Parkwood Blvd., Mansfield, O.
Joel, Irving L., 130 West 47th St., New York 36, N. Y.
Luening, Otto, 405 West 118th St., New York 27, N. Y.
McElyea, Wes W., 1571 Lexington, Muskegon, Mich.
Michael, Richard N., 1052 West 38th St., Erie, Pa.
Moles, Abraham A., 52 Rue Dauphine, Paris 6e, France
Moore, Colin W., Photron, Inc., 20 Railroad Ave., East Northport, L. I., N. Y.
Murry, J. L., Box 9597 Southern Branch P. O., Baton Rouge, La.
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Howard, Calvin R., Brattleboro Rd., Bernardston, Mass.

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Application

AUDIO ENGINEERING SOCIETY

P. O. Box 12, Old Chelsea Station, New York 11, N. Y.

(Check for dues must accompany application)
All information should be printed or typed.

I desire { admission into / advancement in grade in } the Audio Engineering Society. Grade desired.....

.....
Print or Type Name in Full

Born at .....
City *State* *Country* *Date* *Age*

Residence .....
Street *City* *Zone* *State*

Mail Address .....
Street *City* *Zone* *State*

Occupation .....
Position *Name and Address of Concern*

Present Duties .....
State in Detail (Students give school and course)

.....

Past Experience .....
Give Companies, Years, and Positions; use separate sheet for these data if necessary.

.....

.....

.....

Membership in Other Societies.....
Give Names or Abbreviations, and Grade of Membership

.....

EDUCATION

SCHOOL ATTENDED	FROM	TO	COURSE	DEGREE

REFERENCES

While it is preferable for the references to be Society members, this is not indispensable.

Name	*Company and Address*	*Title or Position*
1.		
2.		
3.		

.....
Signature of Applicant

Amount enclosed $.....

.....
Date

ADMISSION REQUIREMENTS

A MEMBER, according to the By-laws, may be any person active in audio engineering who has an academic degree, or its equivalent in scientific or professional experience in the field of audio engineering and its allied arts, and who is familiar with the application of engineering principles and data in that field.

AN ASSOCIATE may be any person interested in the objectives of the Audio Engineering Society and, upon election shall become entitled to all the rights and privileges of the Society except the right to vote or hold office or chairmanship of standing committees.

A STUDENT may be any student interested in audio engineering and enrolled in a recognized school, college, or university. A STUDENT is not eligible to vote or to serve on committees except in his own local section.

Dues, according to the following schedule, should be enclosed with the application:

GRADE	DUES* A	DUES* B	NUMBER OF REFERENCES REQUIRED
Member	$3.75	$7.50	3
Associate	3.00	6.00	2
Student	1.50	3.00	1

* If date of application is October 1 to March 31, use Column B; if date is April 1 to September 30, use Column A; this covers dues through October 30 only.

THE PURPOSE OF THE SOCIETY

The Audio Engineering Society is the organization representing the profession whose field is the recording, transmission, and reproduction of those frequencies audible to the human ear. Its objects are the advancement of the theory and practice of audio engineering and its closely related arts, and the dissemination of important information in this field. The Society seeks to continue the progress which has been made in audio engineering since the days of the original telephone and continuing through the early microphones, loudspeakers, and amplifying devices. Many of the electronic developments familiar to us today, such as broadcasting, sound motion pictures, and radiotelephony, had their beginnings in audio engineering.

Each year, the Society gives the following awards: the John H. Potts Memorial Award for outstanding achievement in the field of audio engineering, the Emile Berliner Award for an outstanding development in the field of audio engineering, and the Audio Engineering Society Award for outstanding work in the advancement of the Society. Honorary Memberships and Fellowships are awarded for past contributions to the profession.

PUBLISHING

Papers presented before conventions or meetings of the Society are often published in the Journal of the Audio Engineering Society, which is sent quarterly, without charge, to all members. Back issues of the Journal are available at reduced member prices. Occasional mailings are also made of news notes for members.

MEETINGS AND SECTIONS

The Audio Engineering Society holds conventions in the fall and winter of each year, during which technical papers are presented and exhibits made by manufacturers of equipment used in the audio field. No charge is made to members for admission to the convention. In addition, local sections have been organized in various parts of the country, and abroad, which meet regularly for the presentation of technical papers and discussion of subjects of interest. Those members desiring to learn of sections in their vicinity or to form new sections should correspond with the Secretary.

COMMITTEES

The following committees are now authorized by the Society: Admissions; Awards; Laws and Resolutions; Convention; Employment Register; Finance; Historical; Lecture Course; Membership; Nominations; Papers Procurement; Publication; Public Relations; Sections; Standards. Qualified members wishing to serve on any of these committees should address the chairman of the committee involved, giving full details of their relevant experience.

OFFICERS

The Society annually elects a President, Executive Vice President, Regional Vice Presidents, Secretary, and Treasurer for one-year terms, and three of the six Governors for a two-year term.

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Application Received	Amount Received	Application to Admissions Committee	Dues Payment to Treasurer	Application Approved by	Date Approved	Card	Past Papers

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A Journal of original record. Papers originally published elsewhere or promised for publication elsewhere are not accepted for presentation at Audio Engineering Society Conventions or for publication in the JOURNAL OF THE AES. In rare instances, exceptions may be made by the Convention and Publications Committees at their discretion.

All papers presented at AES Conventions are automatically considered for publication in the JOURNAL.

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Please do not send black-and-white lantern slides or color transparencies for publication—only photographic prints or original drawings should be submitted.

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Time allotment. The average time allowed for any paper, unless the author requests more time on his Author's Form, is 20 minutes. If you are not going to deliver your paper in person, please supply the name of your alternate to the Convention Chairman as early as possible.

Special oral version. An informal version of approximately 20 minutes, having an air of spontaneity, is usually more effective than a rushed verbatim reading of the manuscript exactly as written for publication. Many authors, after submitting the formal full-length version of their paper for publication, prepare an *informal* version for their guidance during oral delivery.

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Lantern slides. Photographs, diagrams, charts, and curves intended to accompany oral delivery should be in the form of standard American lantern slides (3¼ in. x 4 in.) or 2 in. x 2 in. transparencies. The long dimension of the projected area should be horizontal in the standard slide, but may be either horizontal or vertical in the 2 in. x 2 in. slide.

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Recommended, too, are the following line widths:

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More complete information on lantern slide dimensions is given in American Standard Dimensions for Lantern Slides, Z38.7.19-1950.

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